Heavy Flavour production at RHIC

Sonia Kabana

SUBATECH and University of Nantes, France

QCD@Work, Martina Franca, Italy, 20-23 june 2010

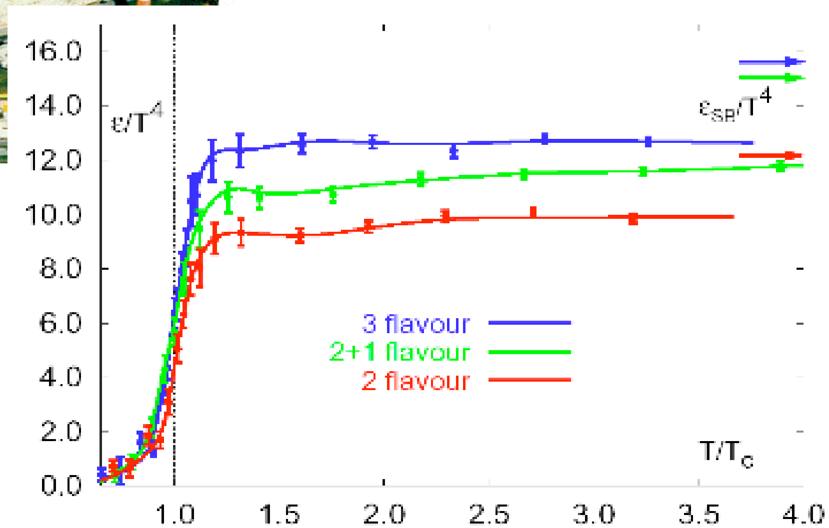
Outline

- Introduction
- Open heavy flavor
  - Charm mesons: D^0
  - Non-photonic electrons
- Quarkonia
  - J/ψ and Υ measurements

Relativistic Heavy Ion Collider

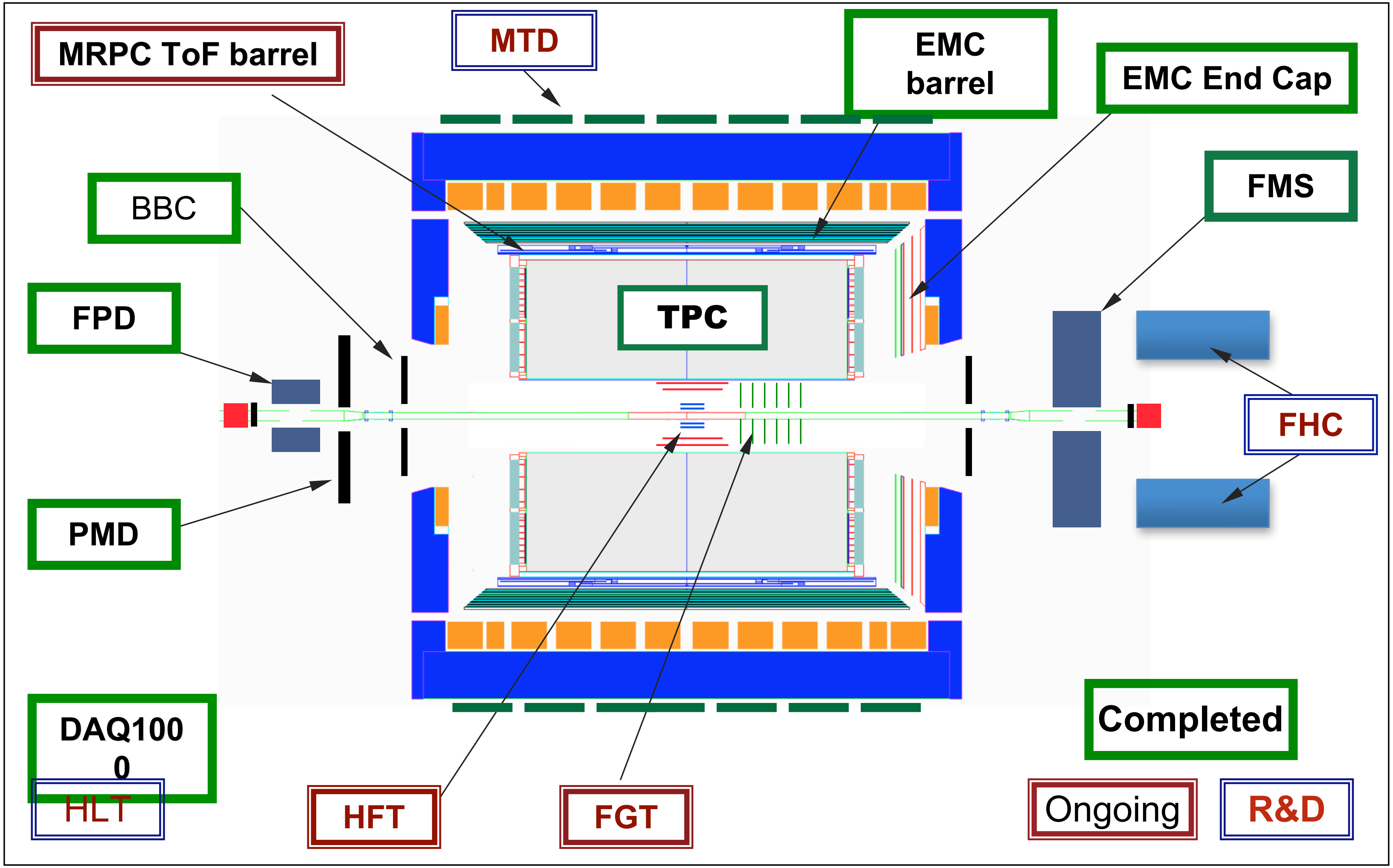
RHIC site in BNL on Long Island, USA

RHIC has been exploring nuclear matter at extreme conditions over the last decade 2000-2010



Colliding systems:
p↑+p↑, d+Au, Cu+Cu, Au+Au
Energies
$\sqrt{s_{NN}}$ = 62, 130, 200GeV
and low energy scan

The STAR Detector



The PHENIX detector

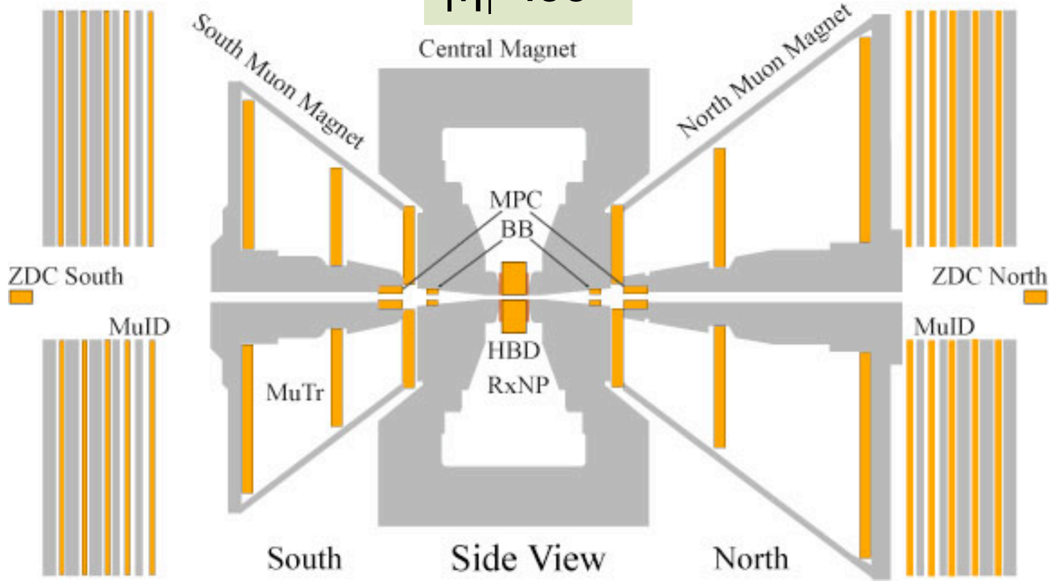
$\mu^+\mu^-$

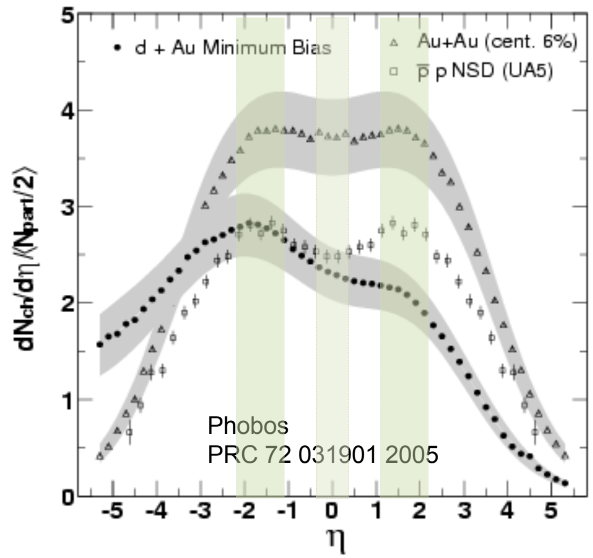
e^+e^-

$|\eta|<.35$

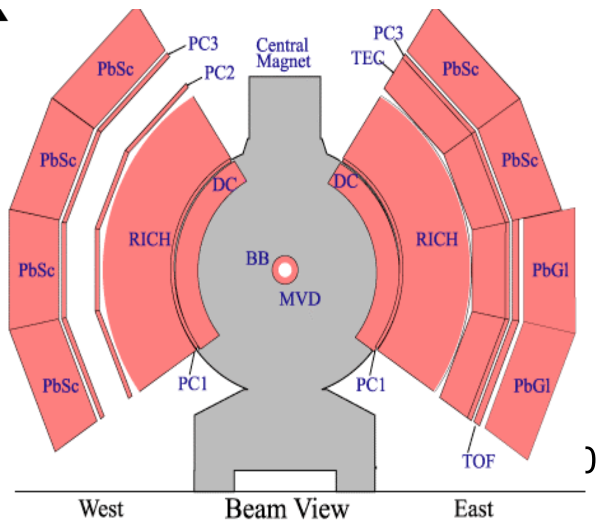
$\mu^+\mu^-$

$1.2>\eta>2.2$





PHENIX

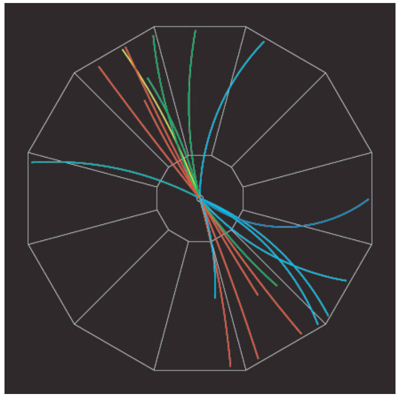


Denis Jouan ,
Renc de Moriond
QCD 2010

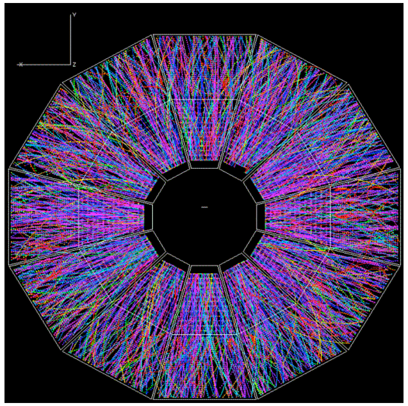
Energy in calorimeter
electron ID in RICH
Tracking in Drift chamber

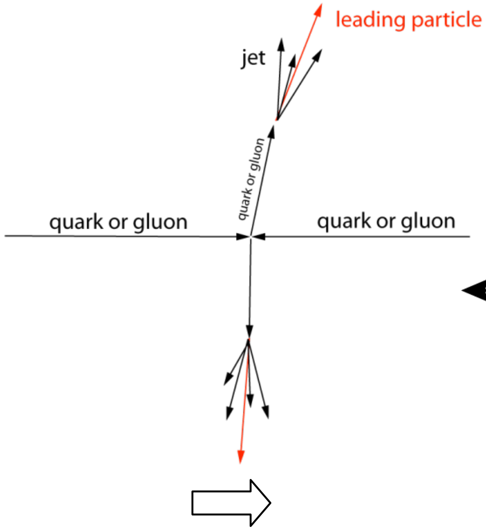
Probing of Dense Matter with jets

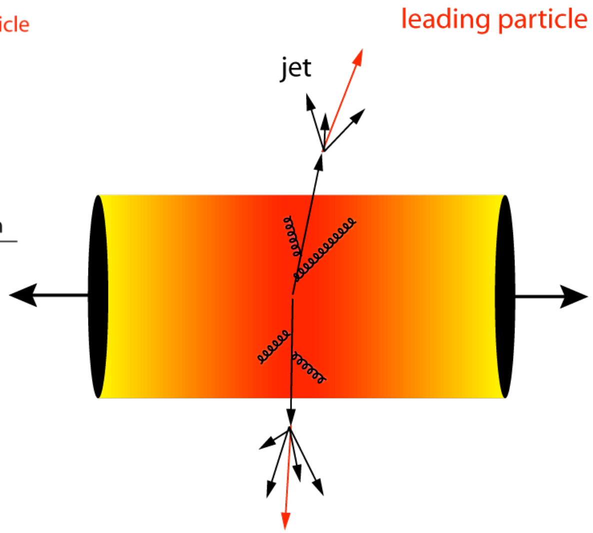
p+p Collision



Au+Au Collision







- nuclear modification factor R_{AA} :

$$R_{AA}(p_T) = \frac{Yield(A+A)}{Yield(p+p) \times \langle N_{coll} \rangle}$$

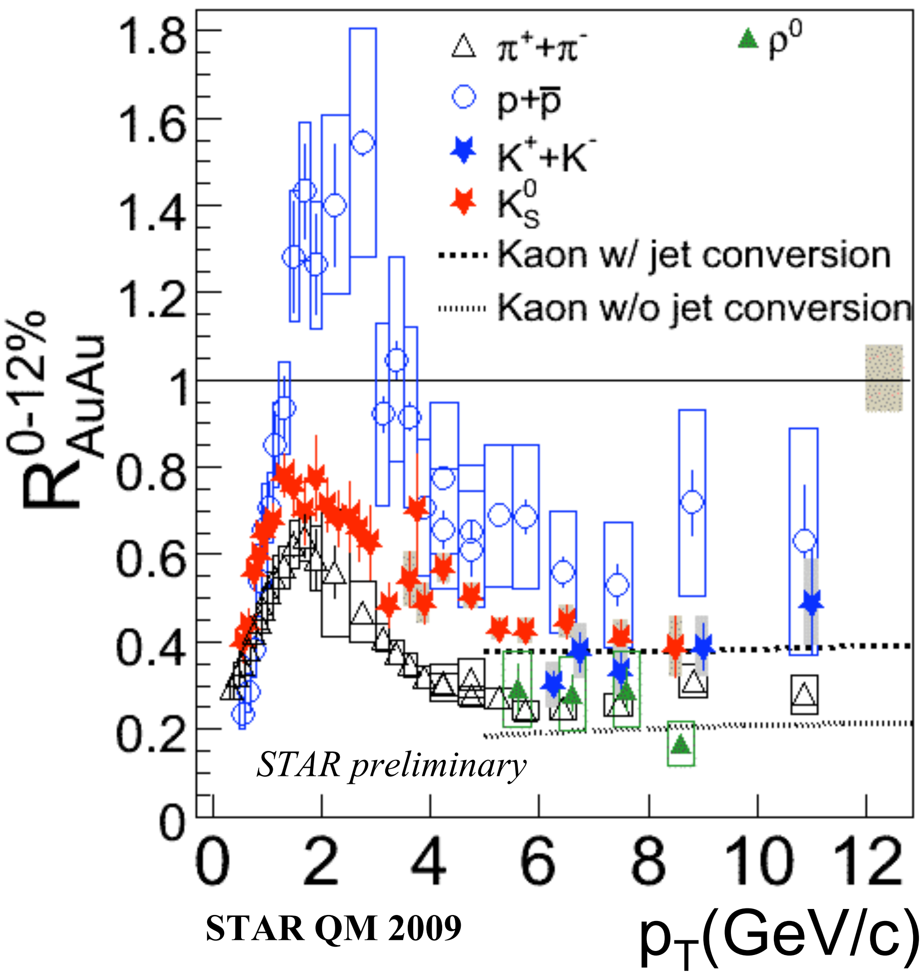
Average number of NN collisions in AA collision

- No "Effect" of nuclear matter: $R_{AA} = 1$ at higher momenta where hard processes dominate
- Suppression: $R_{AA} < 1$

- Partons interact with medium
  gluon radiation/energy loss

- measuring high-p_T particles in Au+Au vs. p+p to extract the properties of medium

Light hadron R_AA in central Au+Au at 200 GeV



STAR QM 2009

- R_AA of u,d,s hadrons is strongly suppressed in central Au+Au at 200 GeV

- **Large energy loss of u,d,s partons in the medium**

Energy loss depends on
properties of medium
(gluon densities, size)
properties of "probe"
(color charge, mass)

What is the flavour dependence of hadron suppression?

Heavy quarks as a probe

- p+p data:

→ baseline of heavy ion measurements
→ test of pQCD calculations

- Due to their large mass heavy quarks are primarily produced by gluon fusion in early stage of collision

→ production rates calculable by pQCD
M. Gyulassy and Z. Lin, PRC 51, 2177 (1995)

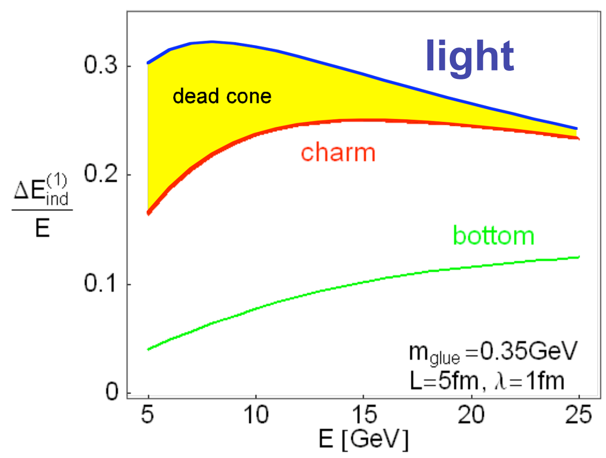
•heavy ion data:

- Studying energy loss of heavy quarks

→ independent way to extract properties of the medium

Radiative energy loss

M.Djordjevic PRL 94 (2004)



Open heavy flavor

Direct: reconstruction of all decay products

$$D^0 \rightarrow K^- \pi^+, \overline{D}^0 \rightarrow K^+ \pi^-,$$

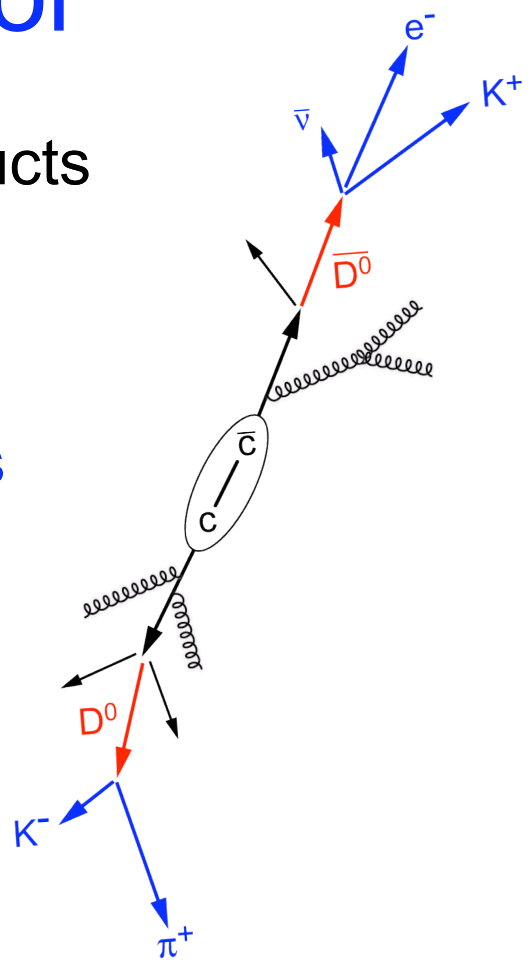
$$B.R. = 3.80 \pm 0.07\%$$

Indirect: charm and beauty via electrons

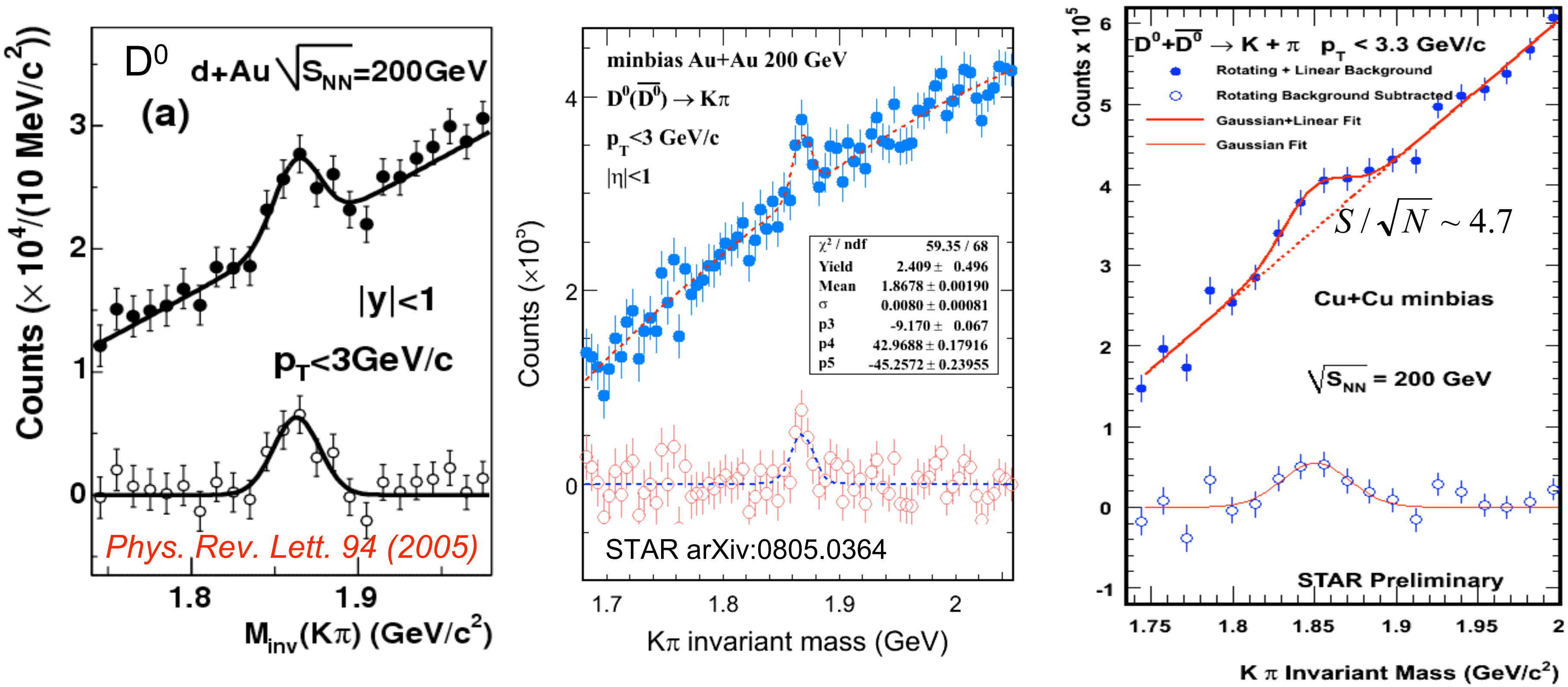
c $\rightarrow$ e^+ + anything (B.R.: 9.6%)
b $\rightarrow$ e^+ + anything (B.R.: 10.9%)
issue of photonic background

charm (and beauty) via muons

c $\rightarrow$ μ+ + anything (B.R.: 9.5%)



Direct D-meson reconstruction at STAR



- $K\pi$ invariant mass distribution in d+Au, Au+Au minbias, Cu+Cu minbias at 200 GeV collisions

First D secondary vertex reconstruction using the STAR silicon detectors ongoing

$AuAu@\sqrt{s_{NN}} = 200\ GeV$ Analysis including Silicon Detectors at low multiplicity

Nr. of tracks < 100

$SVT + SSD > 0$

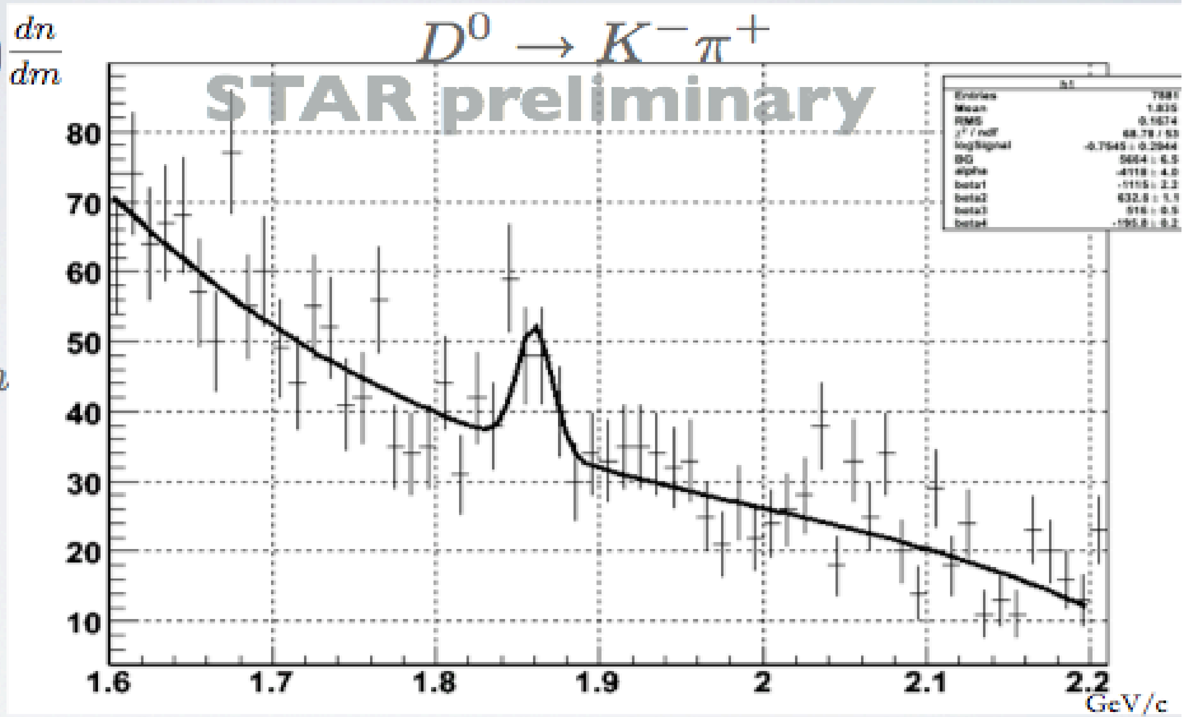
$|\eta| < 1.8$ parent

$|\eta| < 1$ daughters

Decay Length $< 700\ \mu m$

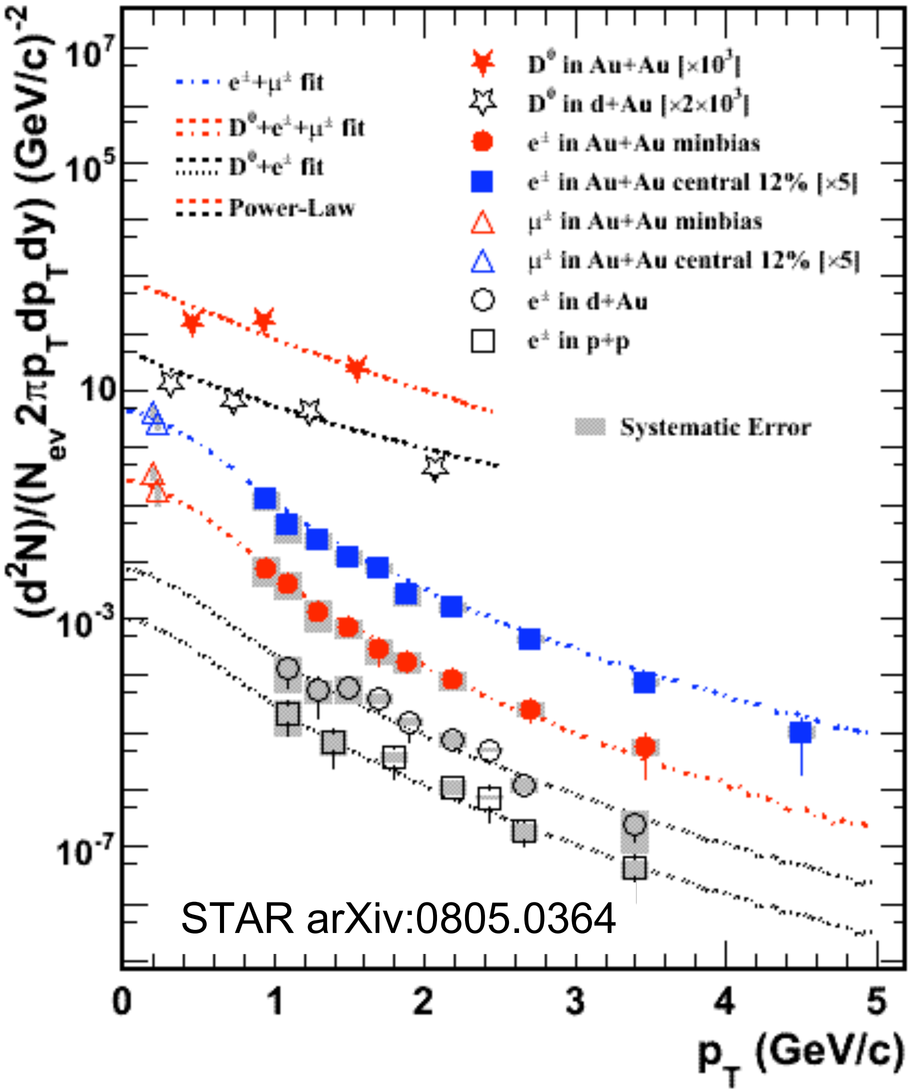
$|vtxZ| < 10\ cm$

$p_T > 0.3\ GeV/c$



A. Geromitsos, (STAR coll.), CIPANP2009

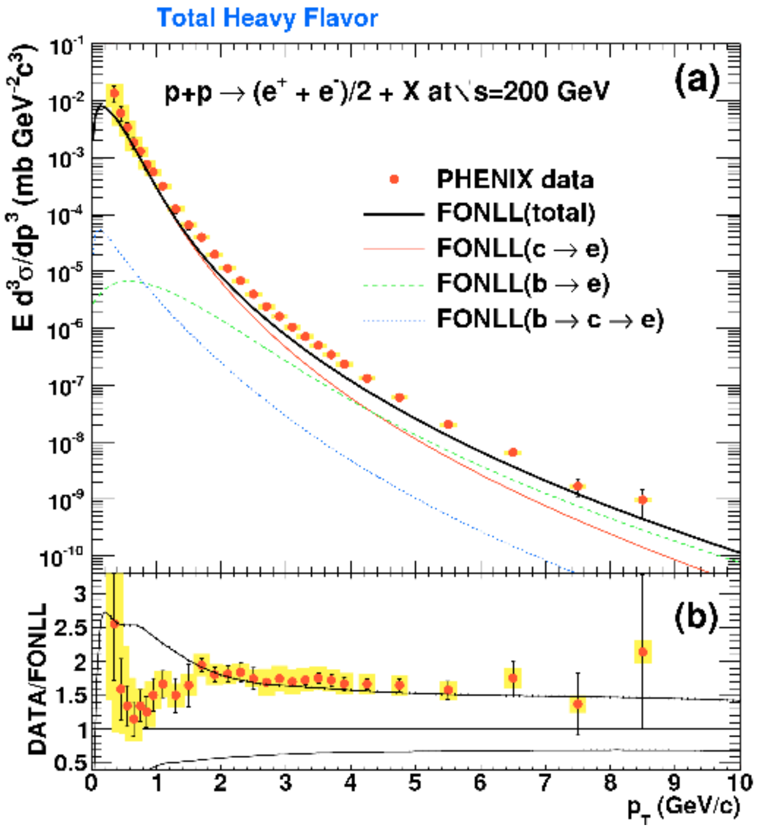
Measurement of charm STAR



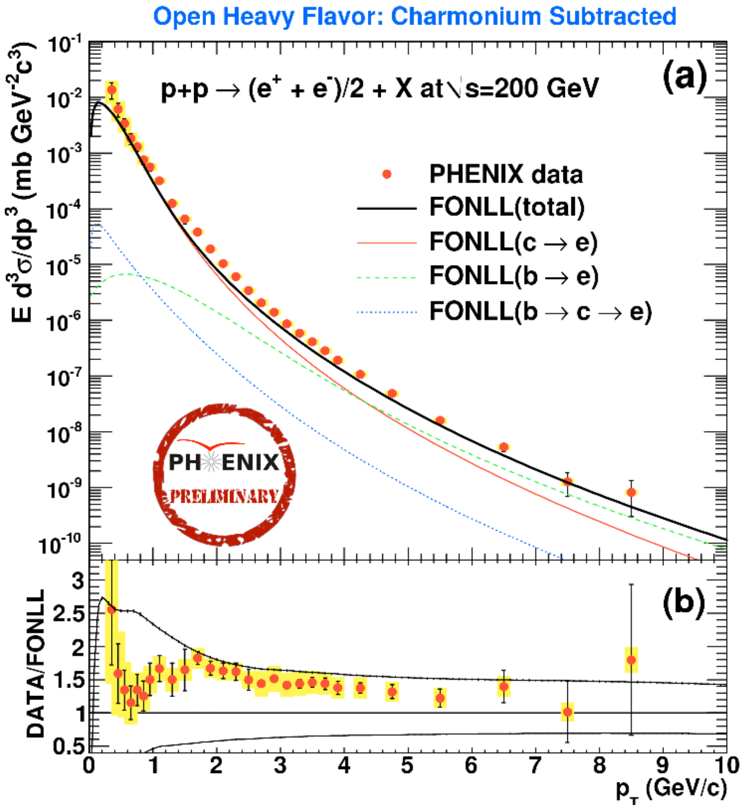
STAR charm measurement:

- D^0 in d+Au, Au+Au, Cu+Cu 200GeV
- low p_T muon in Au+Au 200GeV
- non-photonic electrons in p+p, d+Au, Cu+Cu, Au+Au 200GeV
- 90% of charm total kinematic range covered

Measurement of charm PHENIX

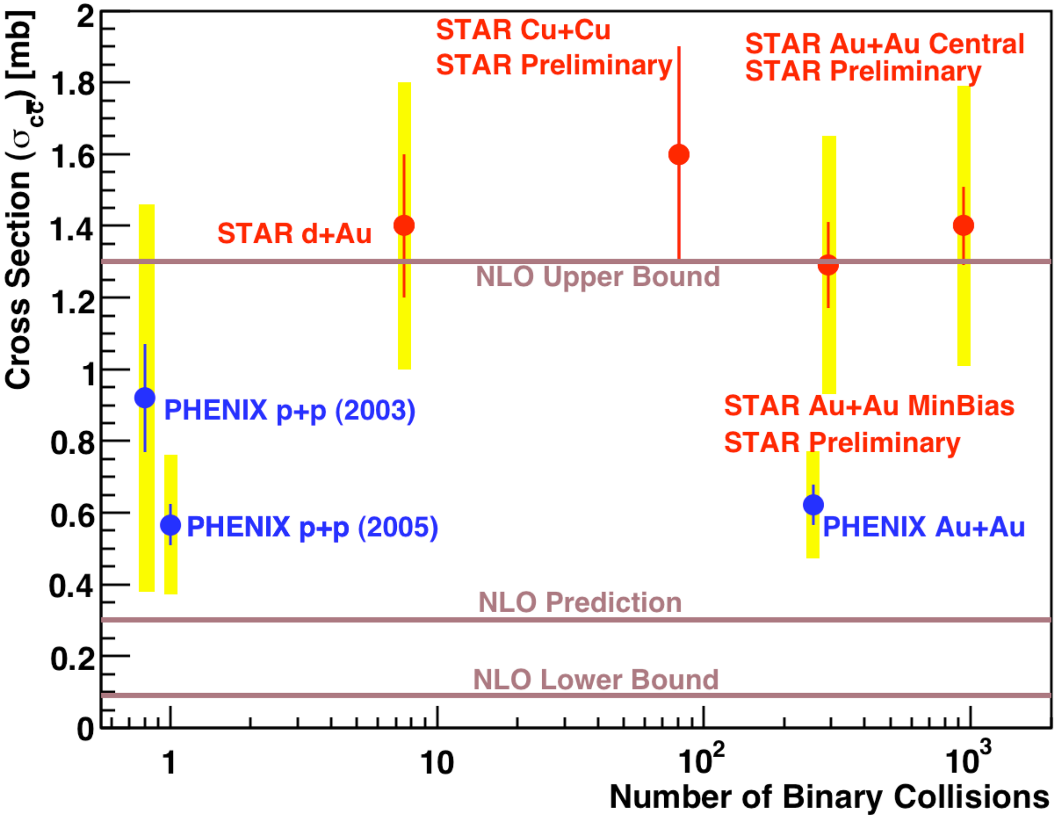


Phys. Rev. Lett. 97, 252002 (2006)



•New study takes J/y→ $e^{\pm}$ contribution into account

Open Charm Cross-section



STAR:

D^0, electrons

PRL 94(2005) 062301

D^0, muons

arXiv:0805.0364

PHENIX:

Single electrons

PRL 97(2006) 252002

Electron pairs

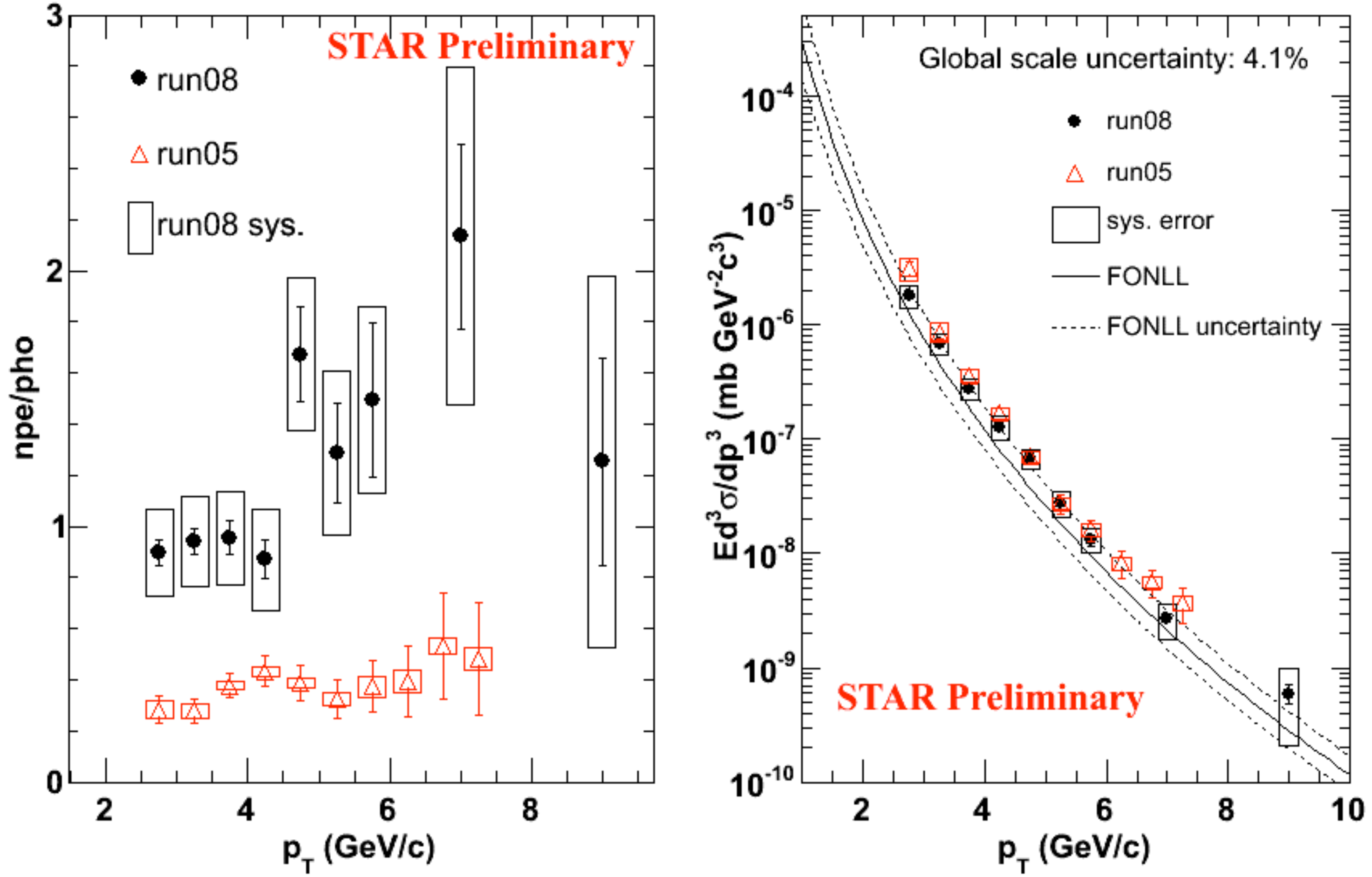
544 ± 39(stat) ± 142 (syst) ± 200 (model)

PLB 670 (2009) 313

- Large discrepancy between extracted total cross-section from STAR and PHENIX

Resolution of the Phenix-STAR discrepancy

New STAR high pT NPE Measurements in 200GeV p+p collisions



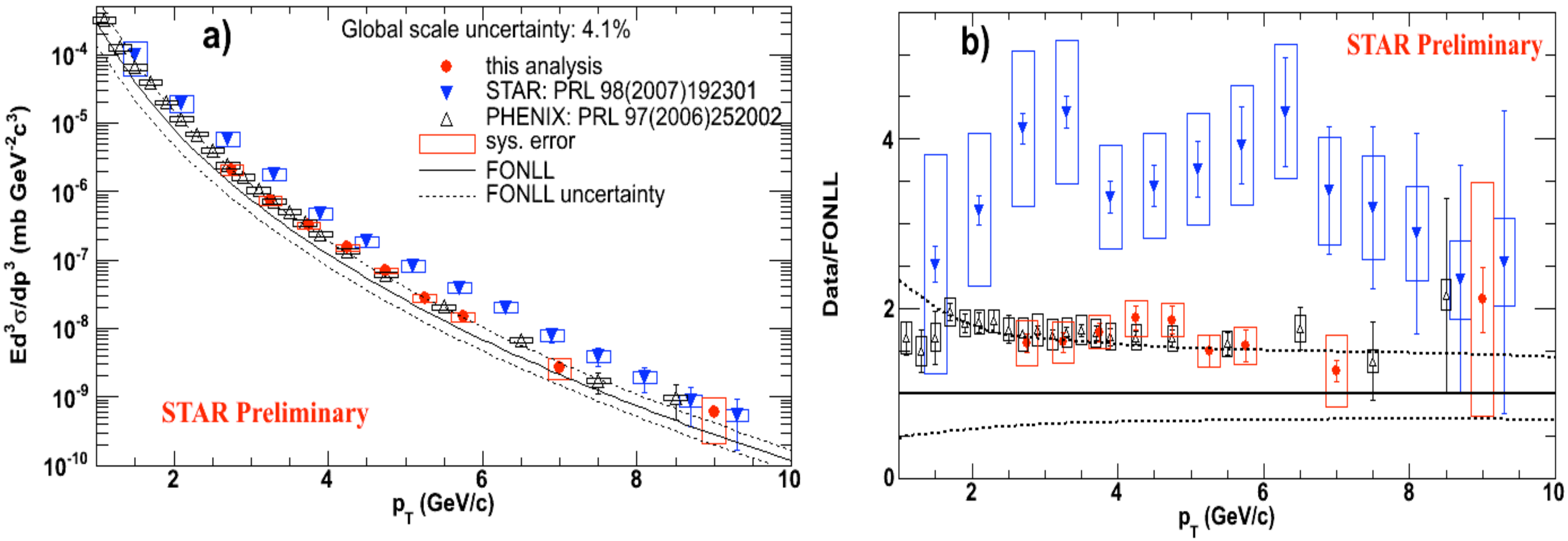
W. Xei et al (STAR), DIS2010

Measurement done using TPC+EMC using run08 and run05 data.

✓**pT>2.5GeV/c NPE measurement with dramatically different background agree with each very well**

Comparison with the Published NPE Results

W. Xei et al (STAR), DIS2010



STAR and PHENIX NPE result in 200GeV p+p collisions

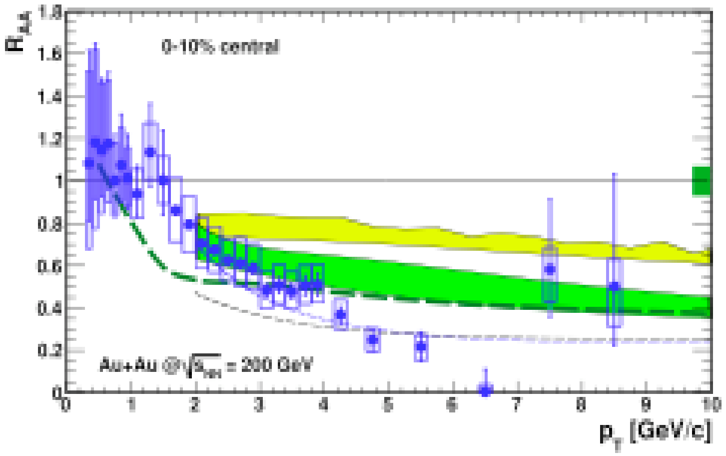
✓Are consistent within errors at pt > 2.5 GeV/c

STAR NPE results are consistent with FONLL in 200GeV p+p collisions

Large suppression of Non-Photonic-Electrons

A Adare et al, PHENIX, arXiv:1005.1627

Au+Au 200 GeV 0-10% central



Thick dashed line: BDMPS (D,B)->e

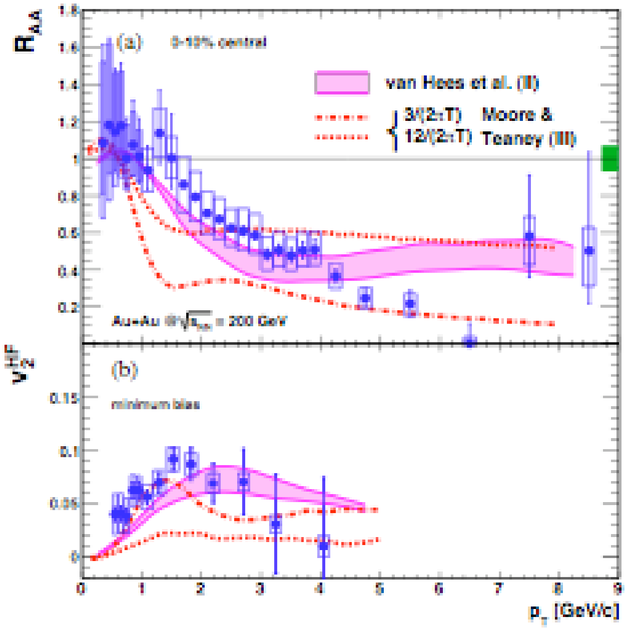
Upper band: DGLV (D<B)->e radiative dedx

Lower band: DGLV collisional+rad. dedx

Thin dashed curves: DGLV only D->e+X

NPE R_AA puzzle: Larger suppression (c+b) than expected for radiative dedx/dead cone effect

Adding collisional dedx improves agreement



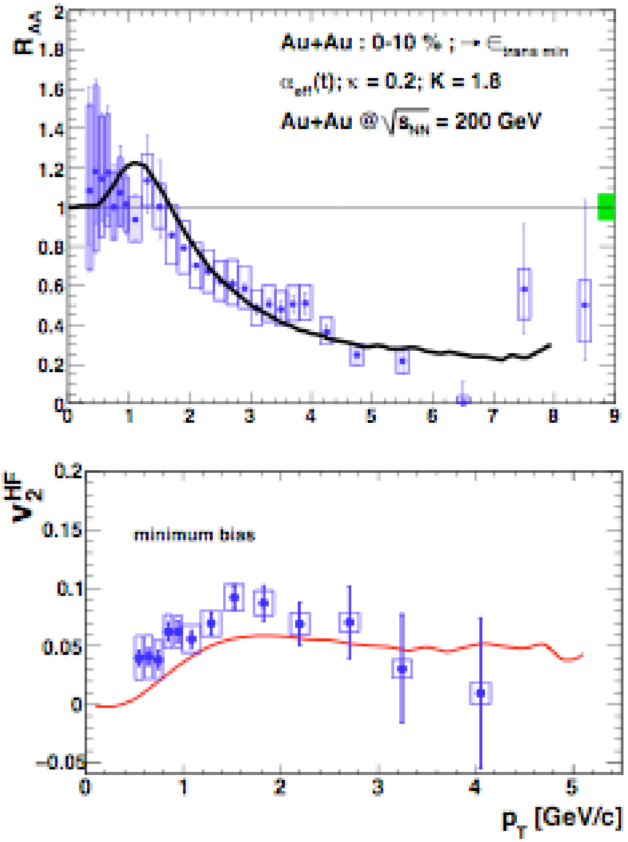
Van Hees et al PRL100 (2008) 192301

Dedx by elastic scattering mediated by resonance excitation of D and B-like states in the medium

Describes ~ both R_AA, v2(NPE)

R_AA(NPE) and v2(NPE)

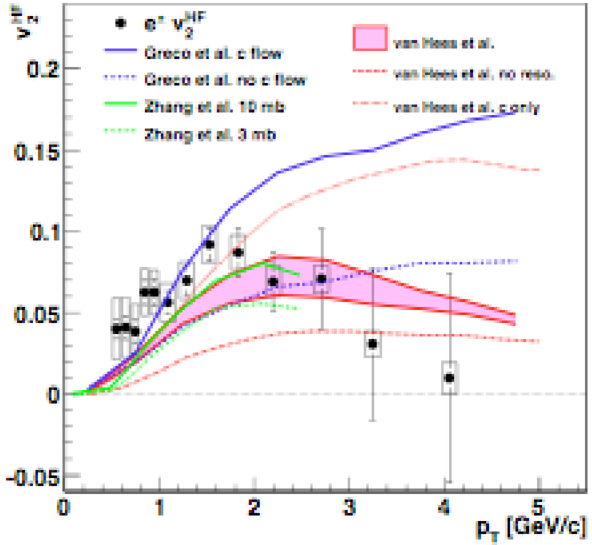
P. Gossiaux, J Aichelin, PRC78 (2008) 014904, 0901.2462, 0901.0946



Collisional dedx+

running coupling constant,

A Adare et al, PHENIX, arXiv:1005.1627



Greco et al: c flow assumes v2(c)=v2(u,d)

no c flow assumes v2(c)=0

Zhang et al: HIJING+(parton cascade)+(hadron cascade) for two charm quark scattering cross sections

Van Hees et al: resonant interaction in strongly interacting QGP and parton coalescence of c,b --> Reduction or flatening of v2 at high pT requires b contribution

Resonances required at low pT

v2(NPE)

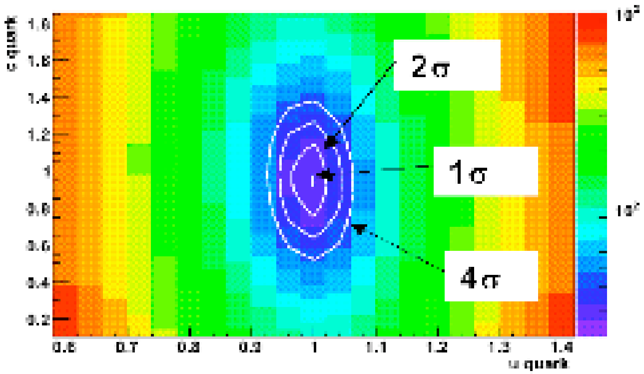
A Adare et al, PHENIX, arXiv:1005.1627

R_AA(NPE) suppression and sizable v2(NPE) :

Heavy quarks lose energy in the medium, while acquiring a substantial component of the medium's collective flow

Compare v2(NPE) to the expected v2(D) from coalescence production.

pT< 2 GeV to be sensitive only to c and not b



chi^2 for v2(c) vs v2(u)

both normalized to measured v2(u)

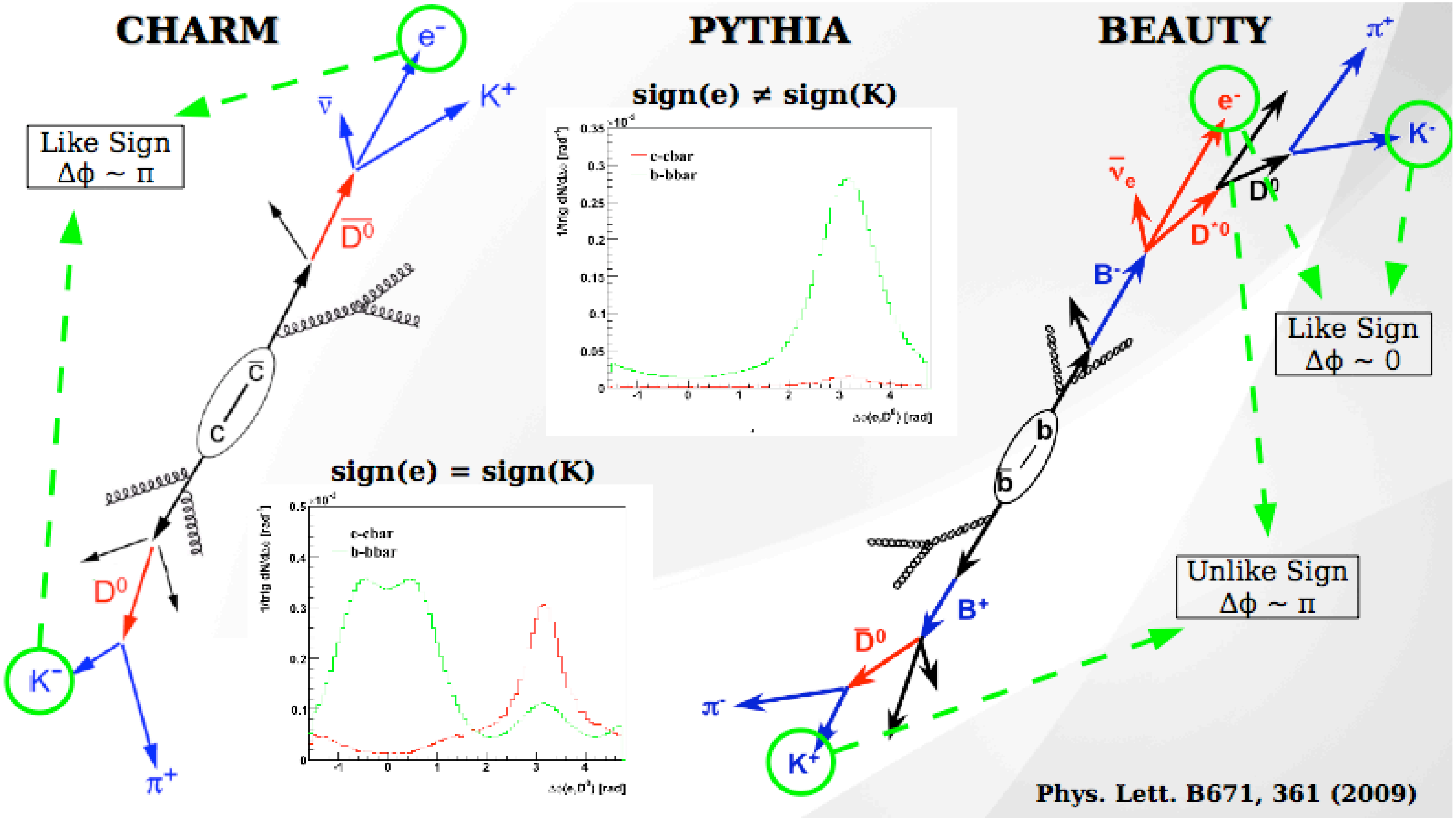
calculated from measured v2(light quarks) and v2(NPE)

→ v2(c) ~ v2(u)

→ the coalescence assumption for D seems supported

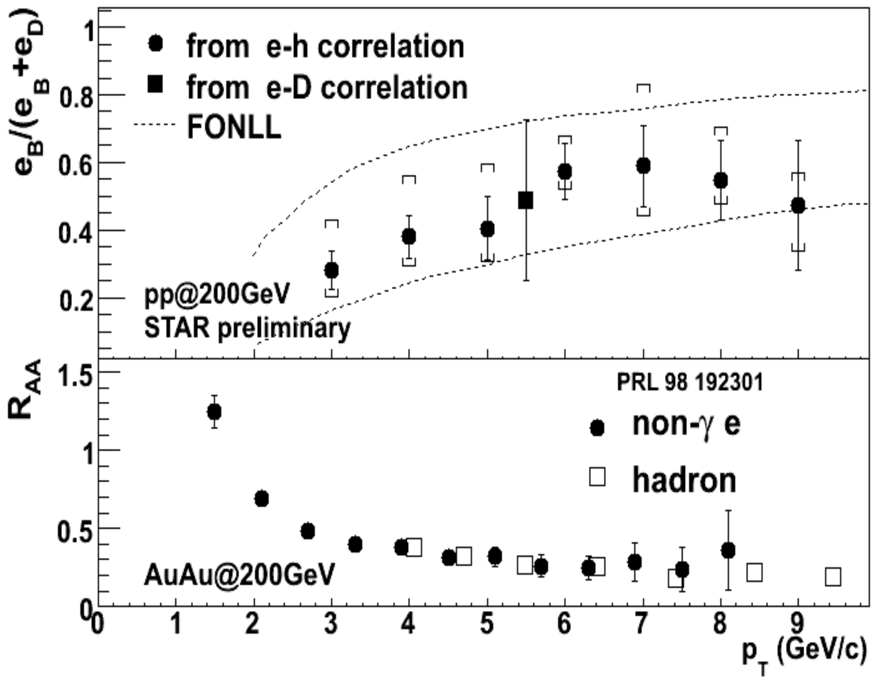
→ indicates common quark collectivity

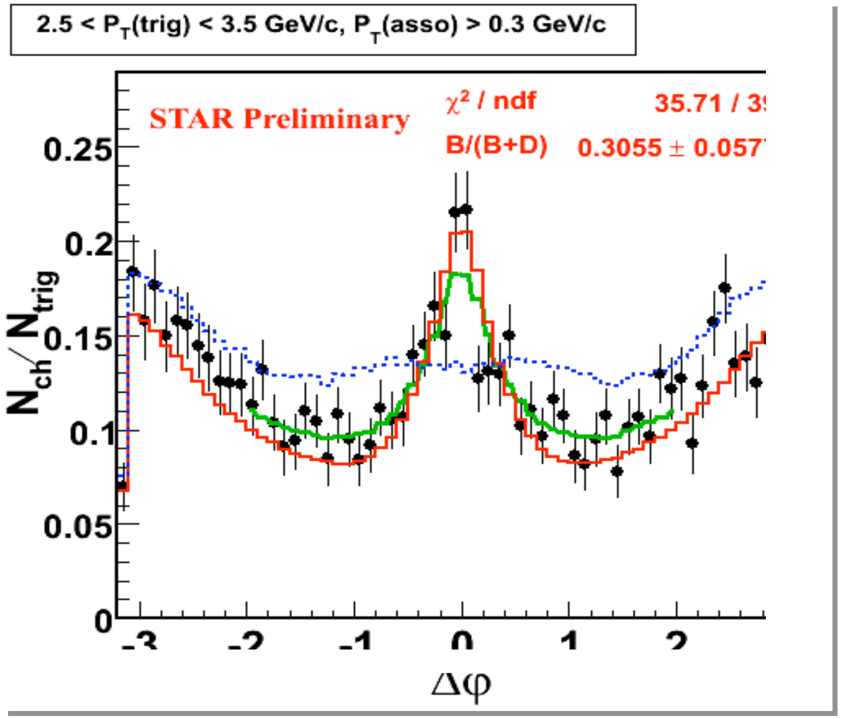
Disentangle c and b with e-D0 correlations



See talk of A Geromitsos, STAR collaboration, tuesday

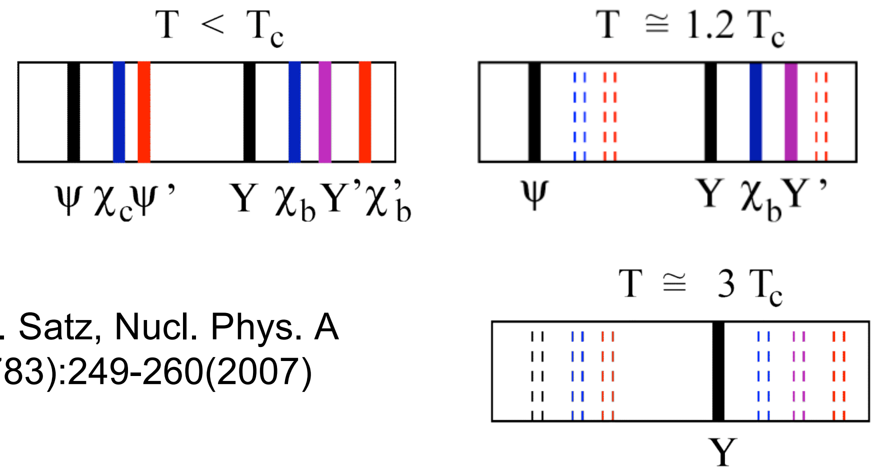
Bottom contribution to electron spectrum



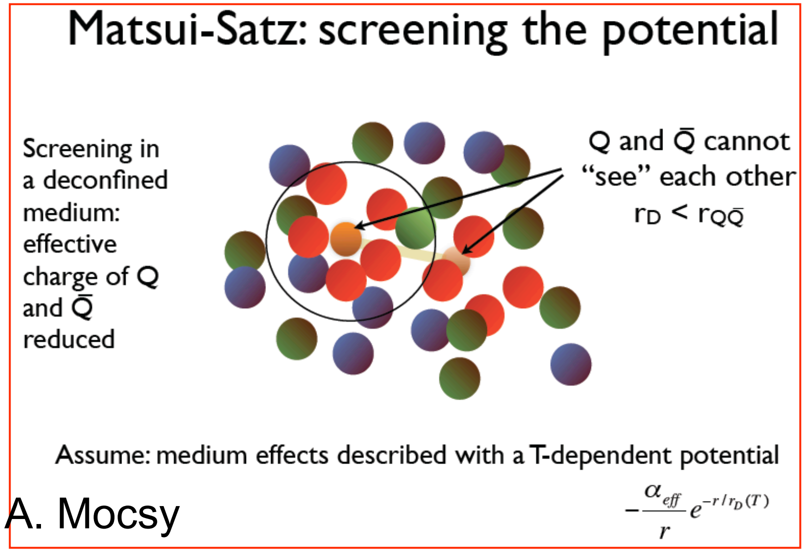


- Difficult to interpret suppression without the knowledge of charm/bottom
- **Data** show non-zero **B contribution** consistent with FONLL
- Charm and bottom contribution comparable at p_T of 5 GeV
- B meson is also suppressed

Quarkonia



H. Satz, Nucl. Phys. A (783):249-260(2007)



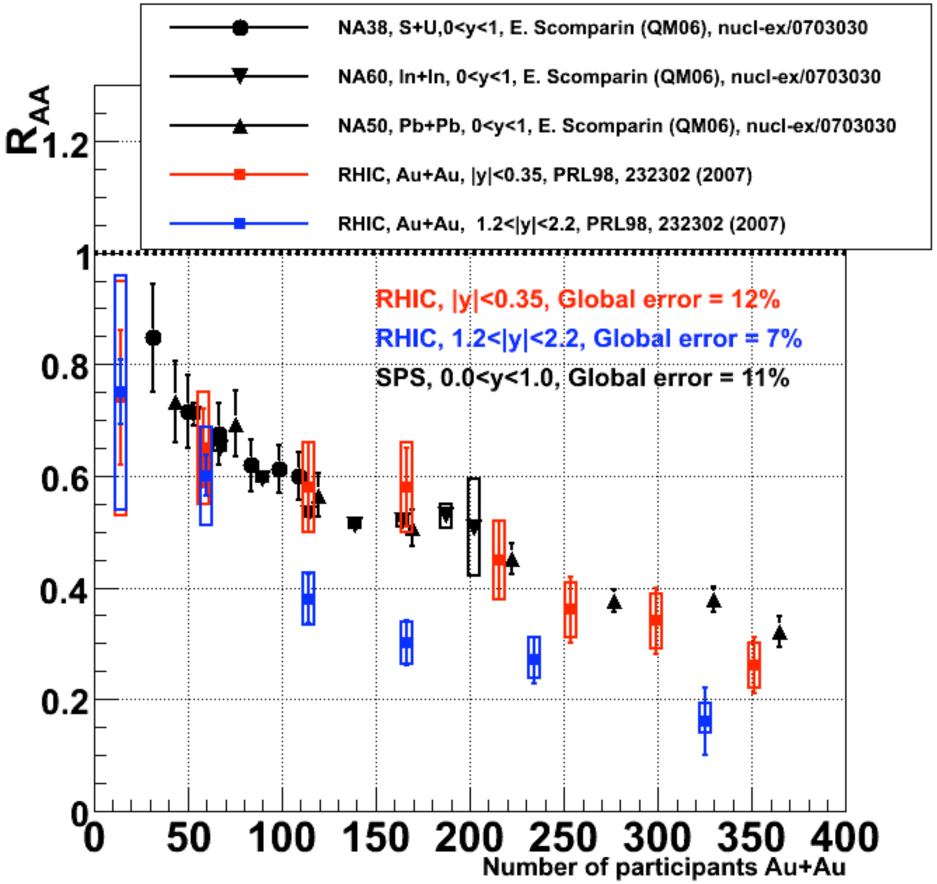
A. Mocsy

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17

Quarkonia: Thermometer of QGP through hierarchy of T(dissociation)

Many effects play a role: dissociation in QGP - cold matter absorbtion - recombination/coalescence from c, cbar - heavy resonances ...

The “RHIC J/ψ puzzle” : y-dependence

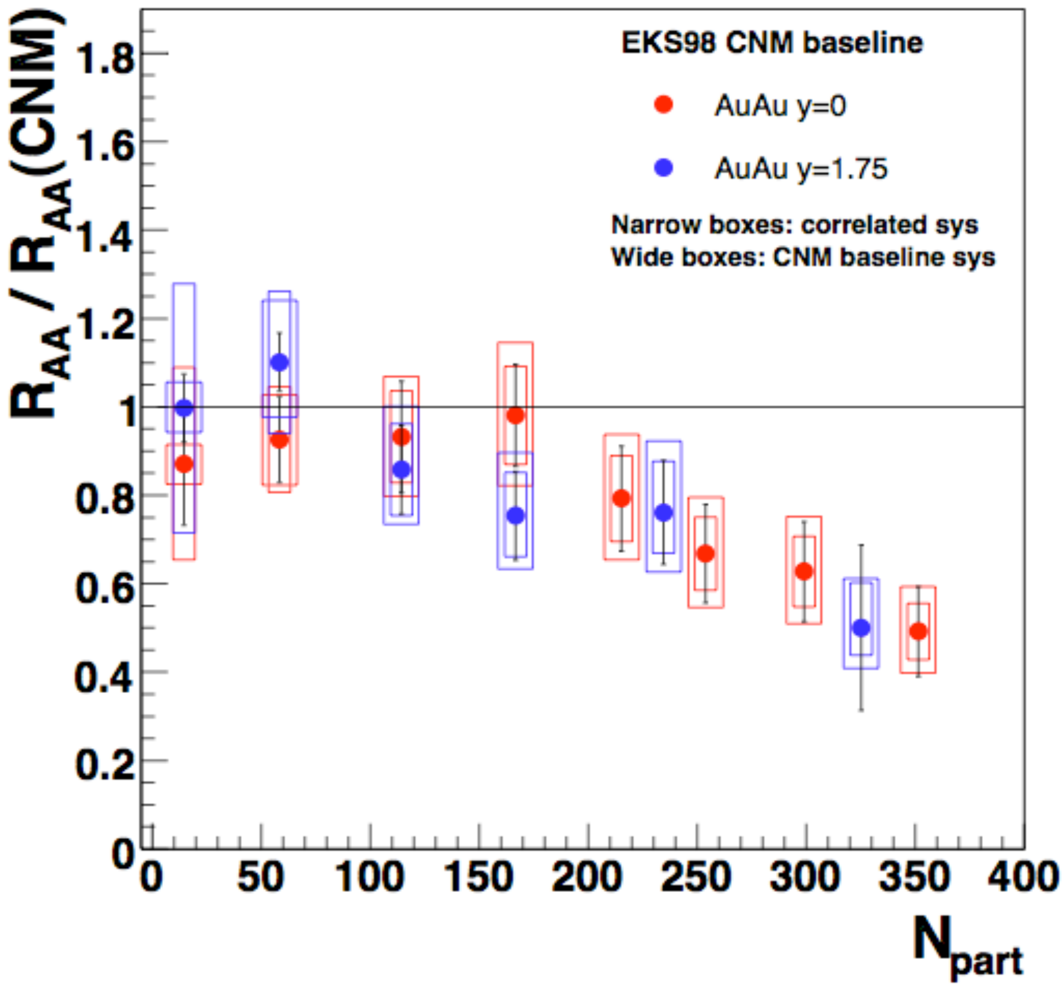


- Suppression doesn’t increase with local density
  - R_{AA} (|y|<0.35) > R_{AA} (1.2<|y|<2.2)
  - R_{AA} (RHIC, |y|<0.35) ≈ R_{AA} (SPS)

R_AA is < 1 also for low N_part where J/Psi (meas./expect) of NA50 was = 1

--> need to correct R_AA for cold nuclear matter effect like done by NA50 with p+A

RHIC J/Psi "y"-puzzle



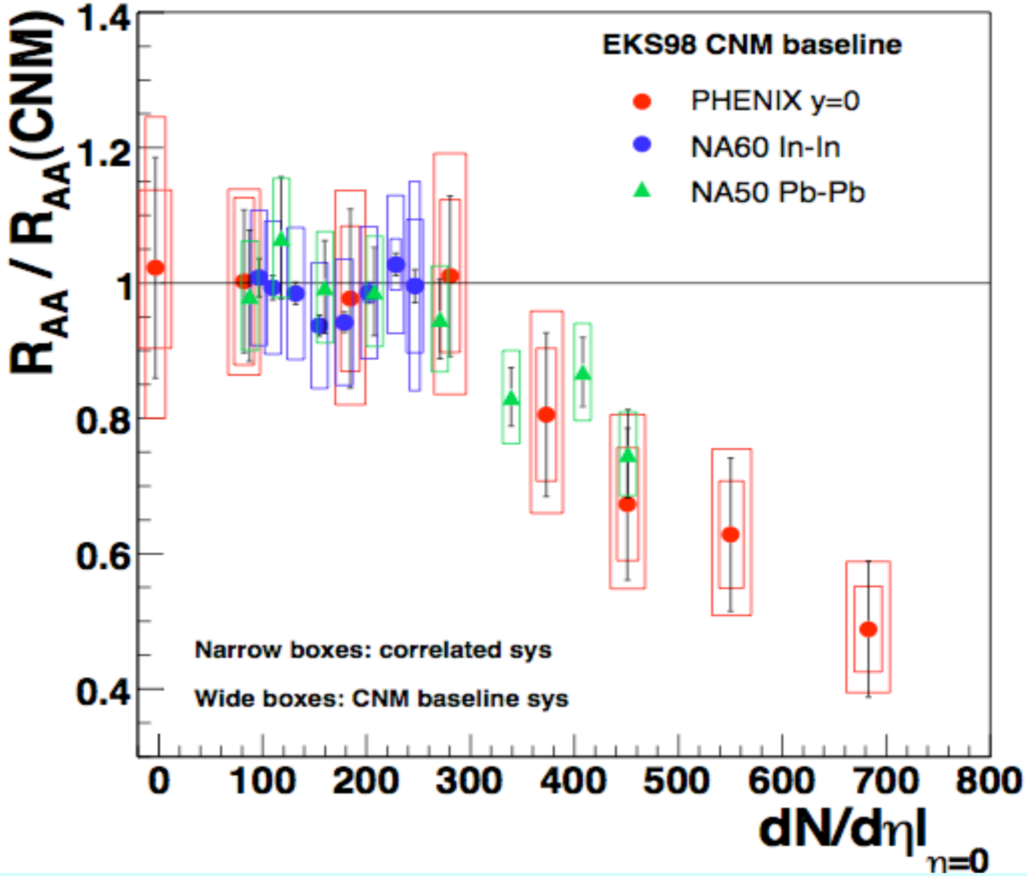
T Frawley, (PHENIX) workshop
ECT*,Trento, May 24-29 2009

Analysis of d+Au data of run 2009 in terms of sigma_abs to account for all nuclear matter effects

→sigma_abs increases from midrapidity to forward rapidity

→ Agreement of J/Psi R_AA/R_AA(Cold N uclear Matter) at y=0 and y=1.75

The J/Psi RHIC-SPS-comparison -puzzle



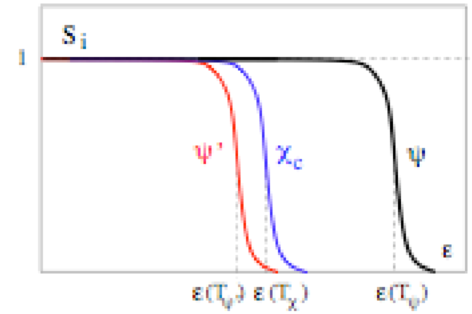
R Arnaldi, D Frawley, Trento 25-29 may 2009

-Divide out cold nuclear matter effects using not model but data (d+Au, p=Au)

- Plot as a function of dN/deta|eta=0 takes into account differences in energy in contrast to N_part.

---> Cold nuclear matter absorbtion effect up to dN/deta|eta=0 = 300

---> Suppression of J/Psi above 300



J/ψ suppression at low p_T maybe from excited stats (ψ', χ_c) F. Karsch, D. Kharzeev and H. Satz, PLB 637, 75 (2006); B. Alessandro et al. (NA50), Eur. Phys. J. C 39 (2005) 335; R. Arnaldi et al. (NA60), Quark Matter 2005; PHENIX: Phys.Rev.Lett.98, 232301,2007.

60% of all J/Psi comes from direct J/ψ. While 30% of all J/Psi come from χ_c and 10% ψ'

χ_c and ψ' T(dissociation) ~Tc, while J/Psi T(dissociation)~ 2.1 T_c

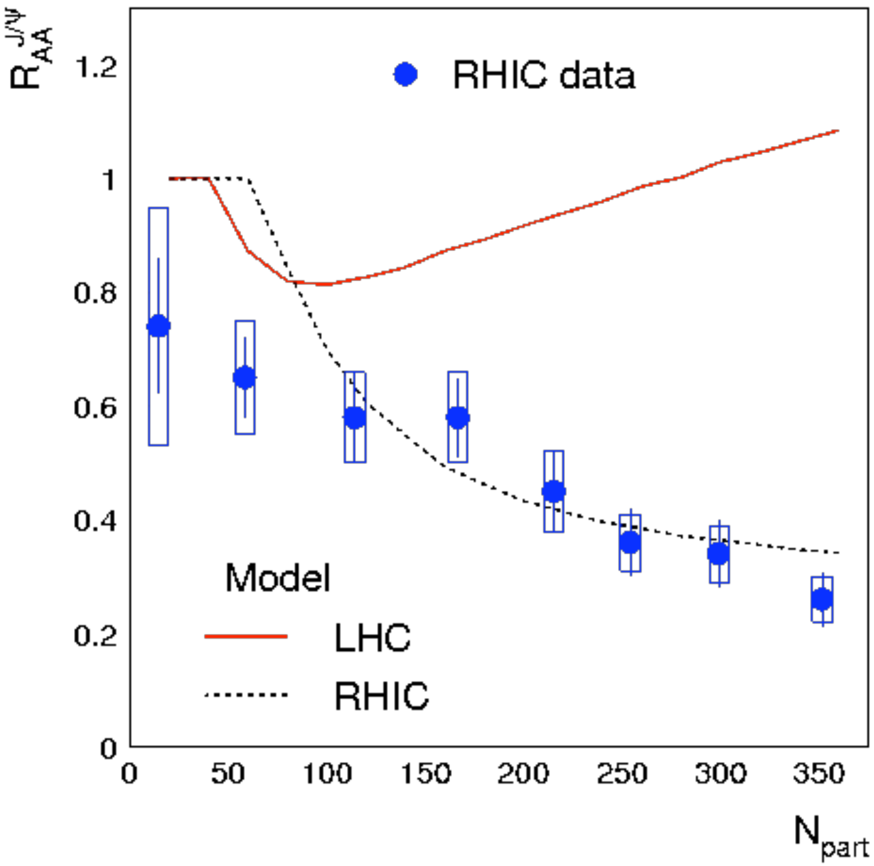
--> suppression of J/Psi observed, maybe due to χ_c and ψ' dissociation

--> directly produced J/Psi may not be suppressed at all at RHIC

--> expect more suppression at LHC due to direct J/Psi dissociation

(but must account for c,cbar coalescence-> J/Psi)

J/Psi assumed completely suppressed and resurrected by c,cbar "coalescence"



A Andronic et al, Phys Lett B 652 2007, p 259

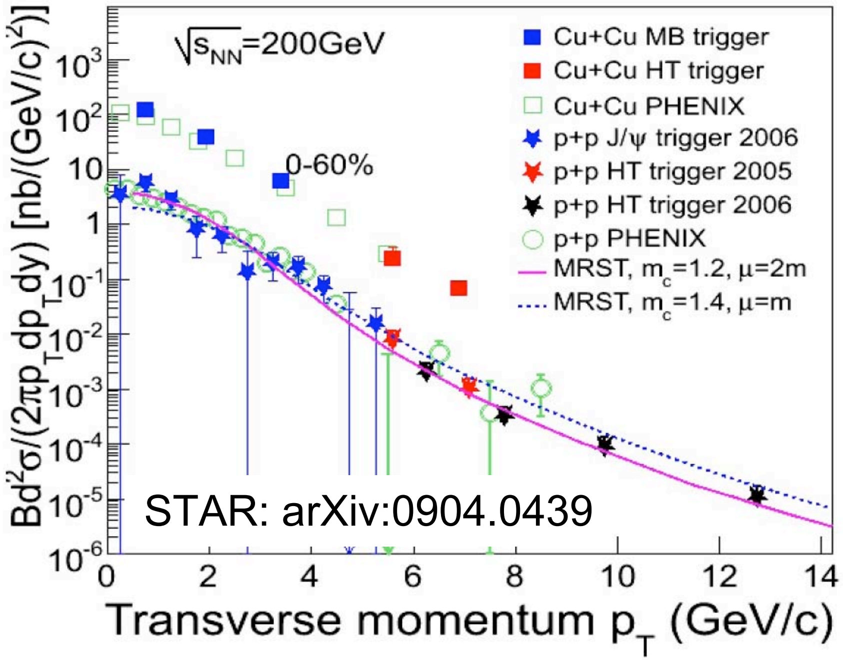
-J/Psi is assumed to be completely suppressed at RHIC

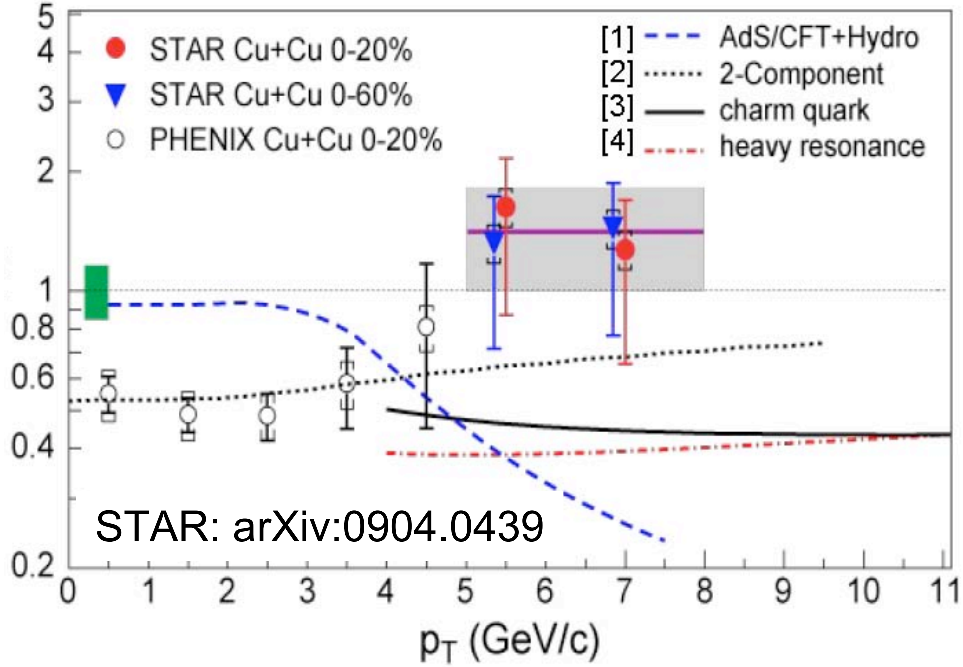
- R_AA(J/Psi) is then estimated for the process of c, cbar coalescence to J/Psi, within a thermal model

→This estimate agrees with R_AA(J/Psi) at RHIC

→ It predicts a great enhancement of R_AA(J/Psi) at LHC

J/ψ in p+p and Cu+Cu 200 GeV





- **$R_{AA}(p_T>5$ GeV/c$) = 1.4\pm 0.4\pm0.2$**
- Consistent with no suppression at high p_T

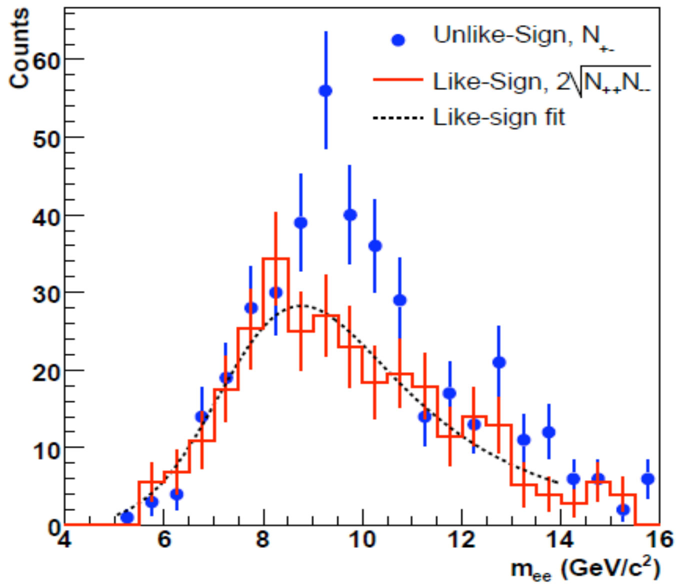
A. Adil and I. Vitev, Phys.Lett. B649, 139 (2007),
S. Wicks et al., Nucl. Phys. A784, 426 (2007)

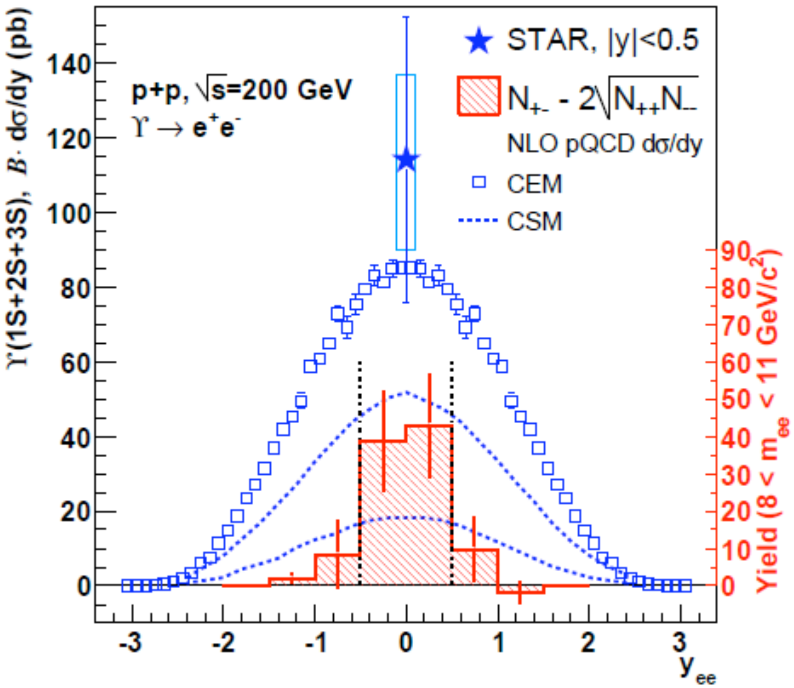
- Inconsistent with AdS/CFT+Hydro and "heavy resonance" models

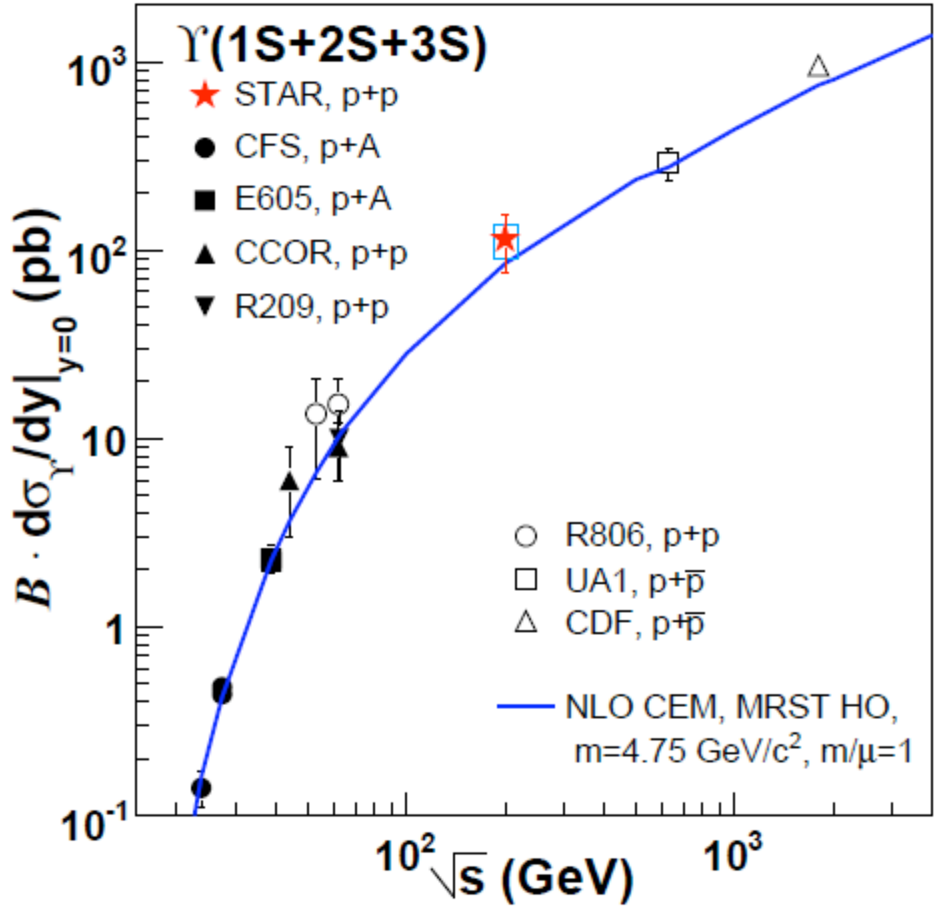
- Two component model+J/ψ form. time+ B feed down describes the trend well

R. Rapp, X. Zhao, nucl-th/0806.1239

STAR Υ measurements in p+p



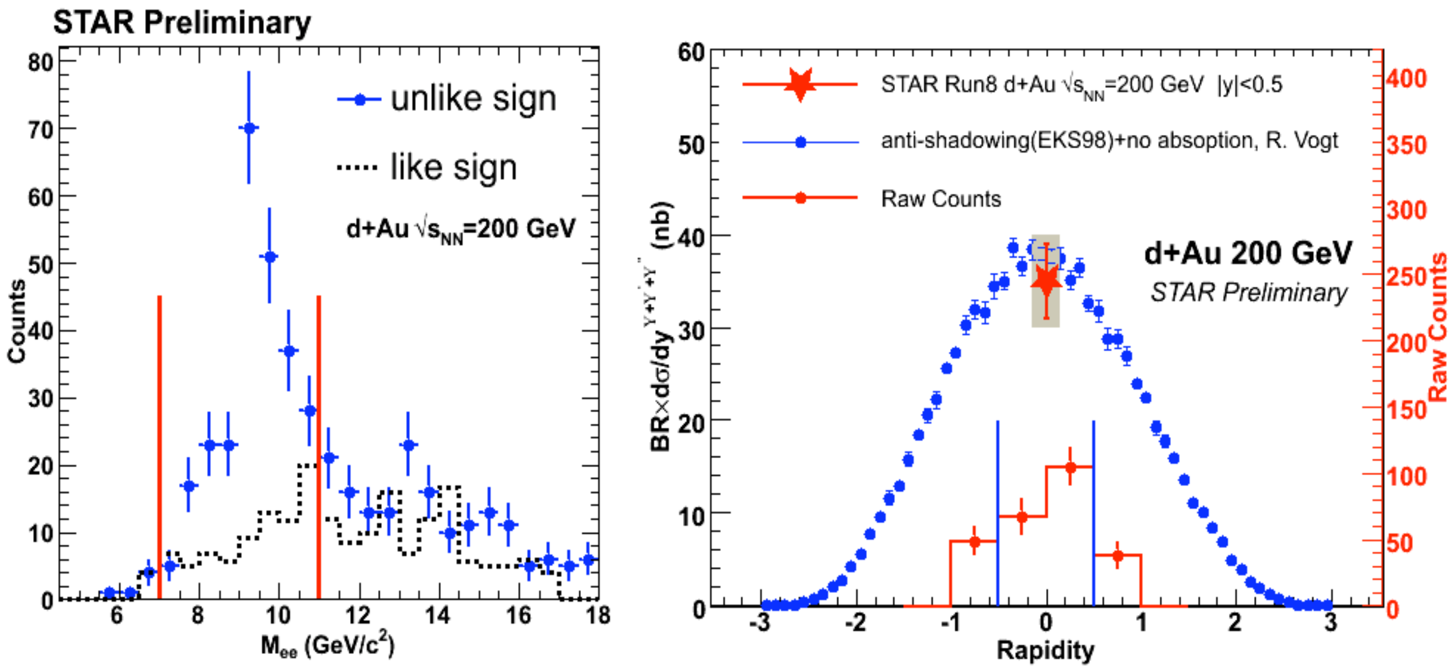




STAR: arXiv:1001.2745

$$B_{ee} \frac{d\sigma}{dy}\bigg|_{y=0} = 114 \pm 38(stat)^{+23}_{-24}(sys) \quad \text{pb}$$

Υ signal in d+Au 200 GeV collisions

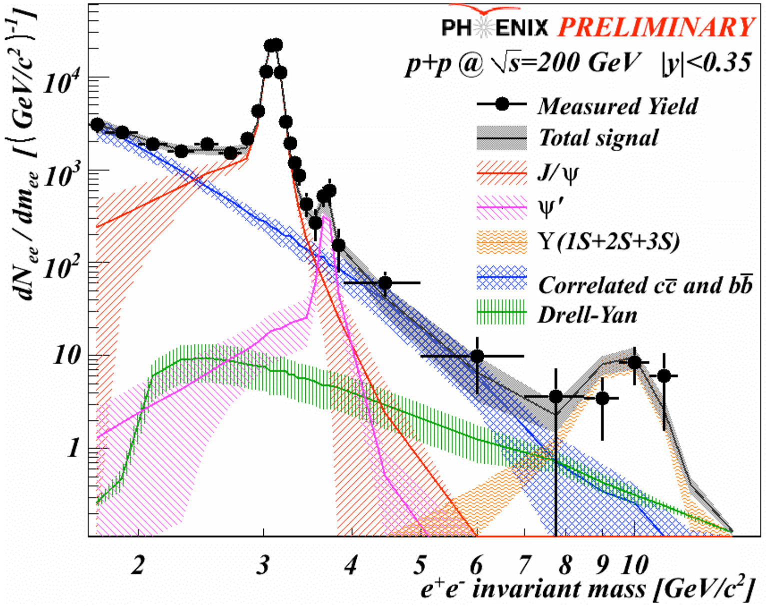


- Strong signal (8σ significance) extracted

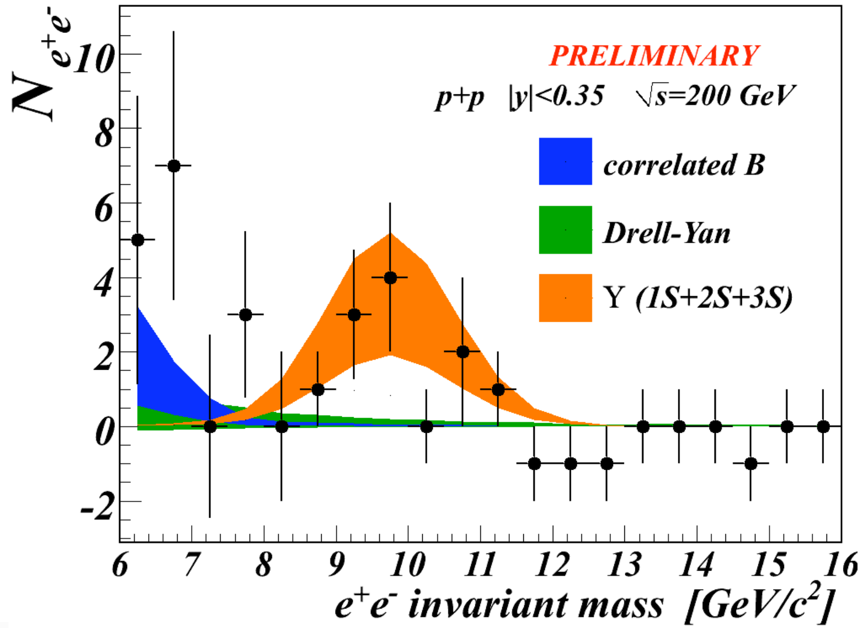
$$R_{dAu} = 0.98 \pm 0.32\ (\text{stat.}) \pm 0.28\ (\text{sys.})$$

- Consistent with N_{bin} scaling of cross-section p+p $\longrightarrow$ d+Au 200GeV

Upsilons in p+p - PHENIX

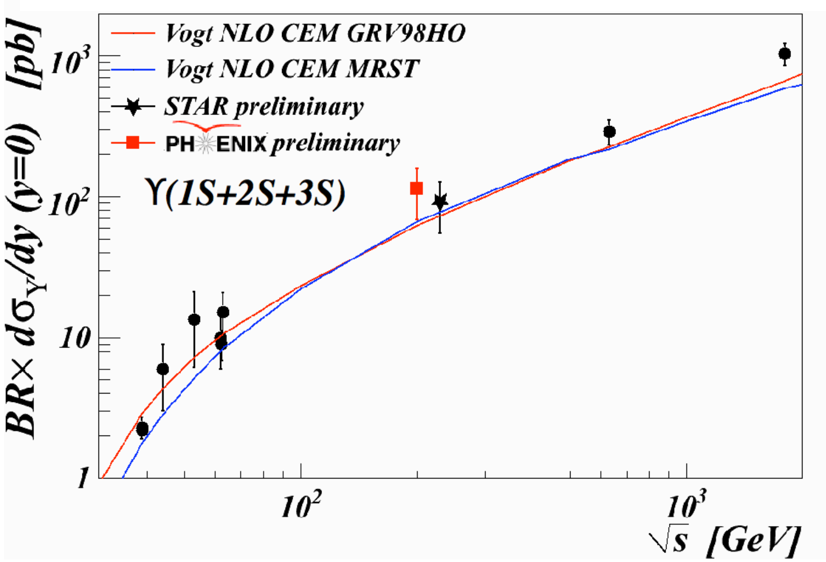


Nucl.Phys.A830:331C-334C,2009.

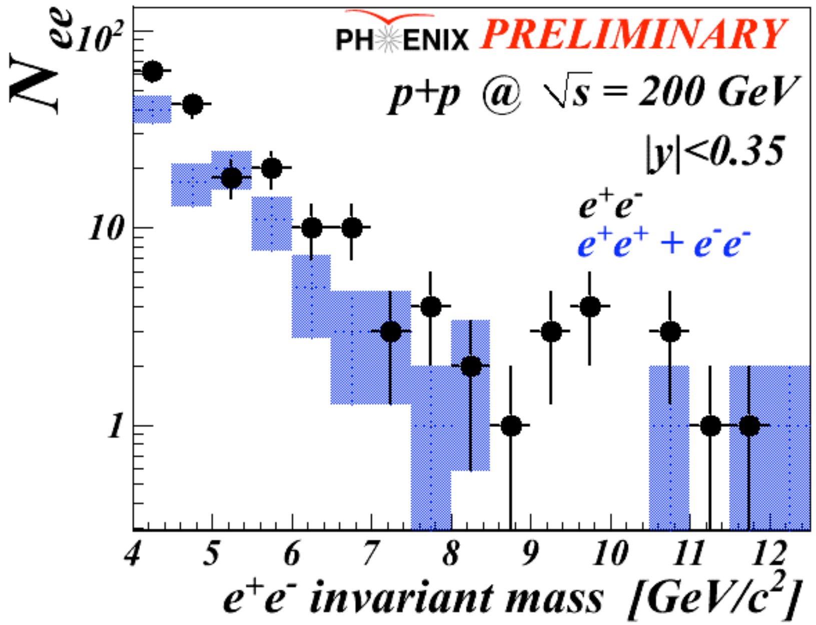


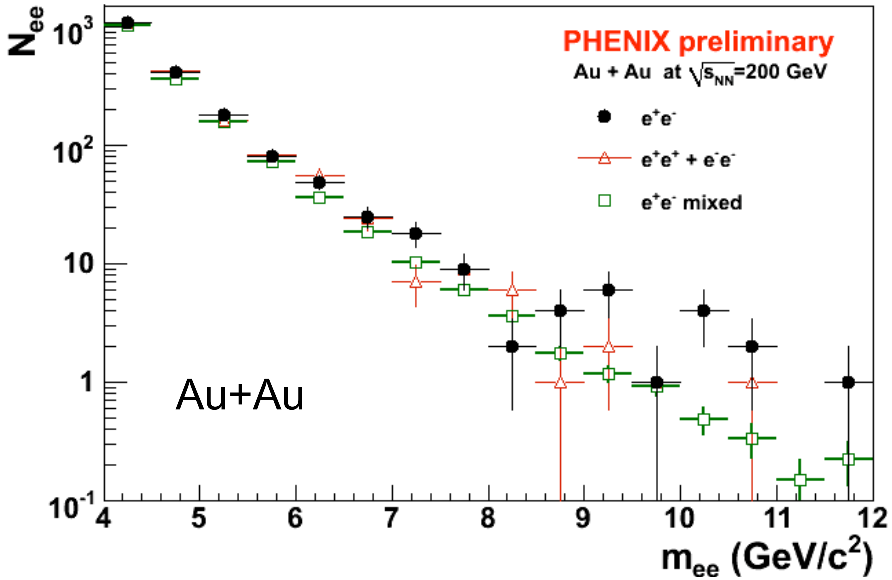
- Cross section follows world trend
- Baseline for Au+Au

$$BR * \frac{d\sigma}{dy}\Big|_{|y|<0.35} = 114^{+46}_{-45}\ pb$$

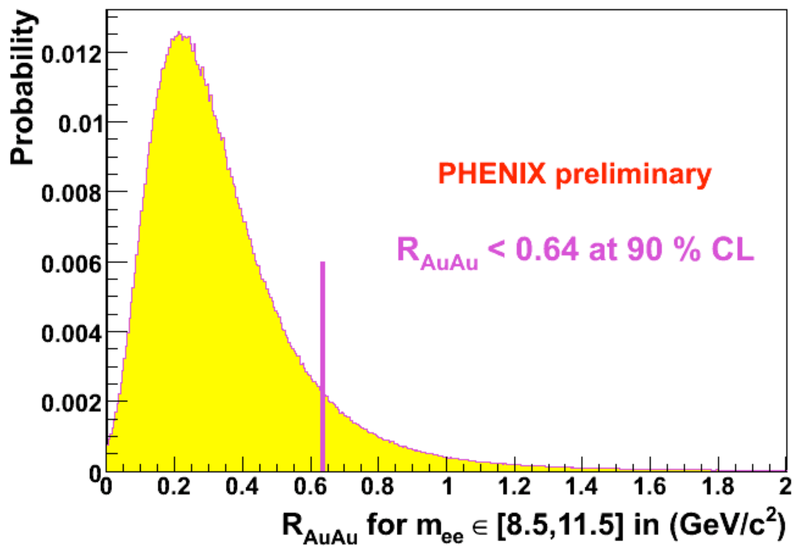


Upsilons Suppressed in Au+Au - PHENIX





R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.



Nucl.Phys.A830:331C-334C,2009.

Conclusions

* Large R_AA and flow of NP electrons in central Au+Au collisions at 200 GeV
Heavy quarks lose energy in the medium, while acquiring a substantial component of the medium's collective flow

* e-h, e-D0 correlations : In p+p at 200 GeV c~b contribution at pT ~5 GeV

c/b contribution in p+p is consistent with FONLL

b is also suppressed in Au+Au at 200 GeV

* J/Psi y-puzzle can be attributed to cold nuclear matter absorbtion :more data needed

* J/Psi sqrt(s) dependence from SPS to RHIC : remains to be understood

Chi_c, psi' suppressed, direct J/Psi not suppressed at RHIC ?

Direct J/Psi also suppressed at RHIC and produced through c,cbar coalescence?

* High pT J/Psi is consistent with no suppression (Cu+Cu 200 geV)

* Y measured in p+p, d+Au, Au+Au

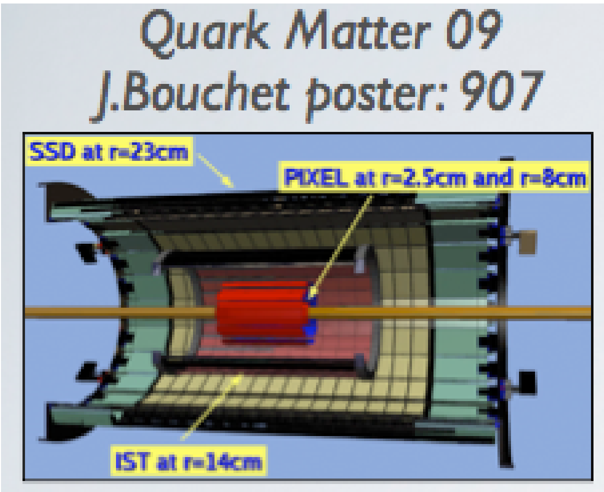
Outlook

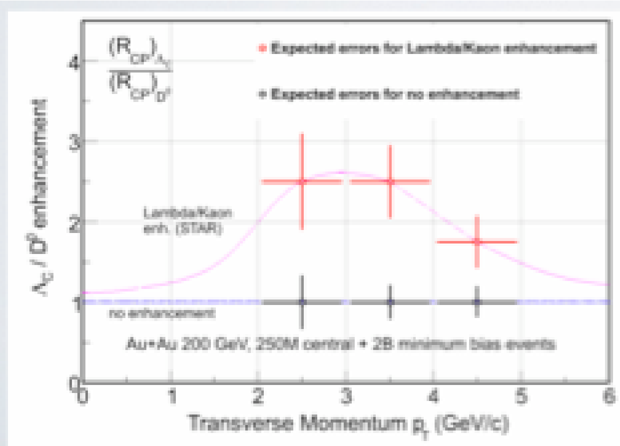
* 2009/2010 STAR run with full TOF , low material -> improve c,b ID

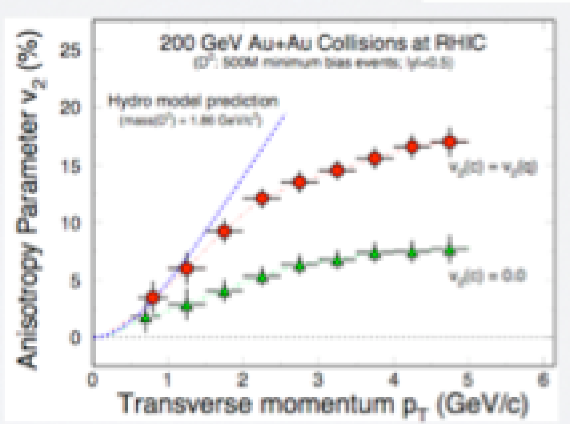
* Both Phenix and STAR plan for silicon vertex detector upgrades to measure Heavy Flavour with great accuracy

--> Heavy Flavour substantial element of RHIC plans

STAR Heavy Flavour Tracker : ~2014

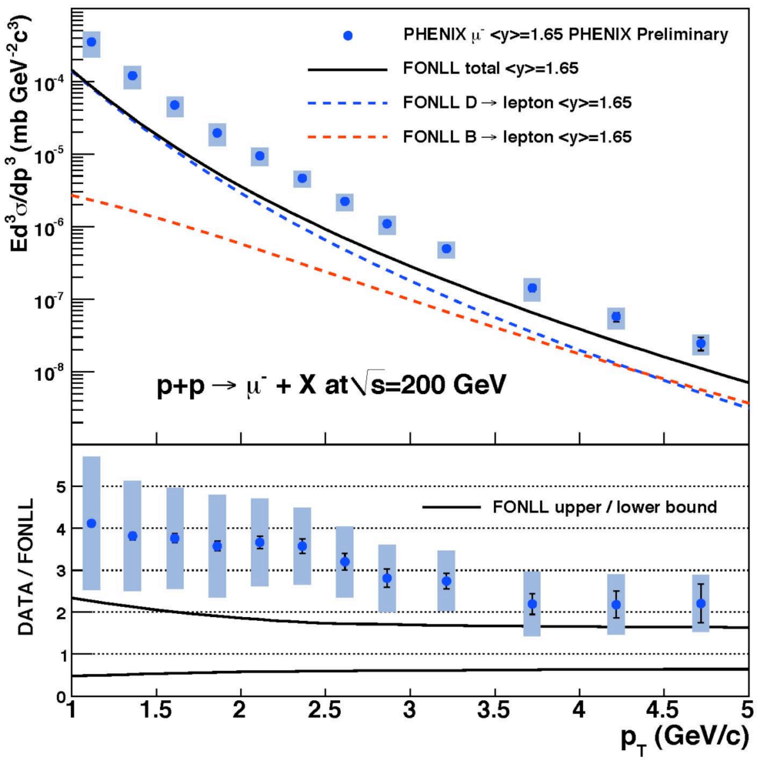


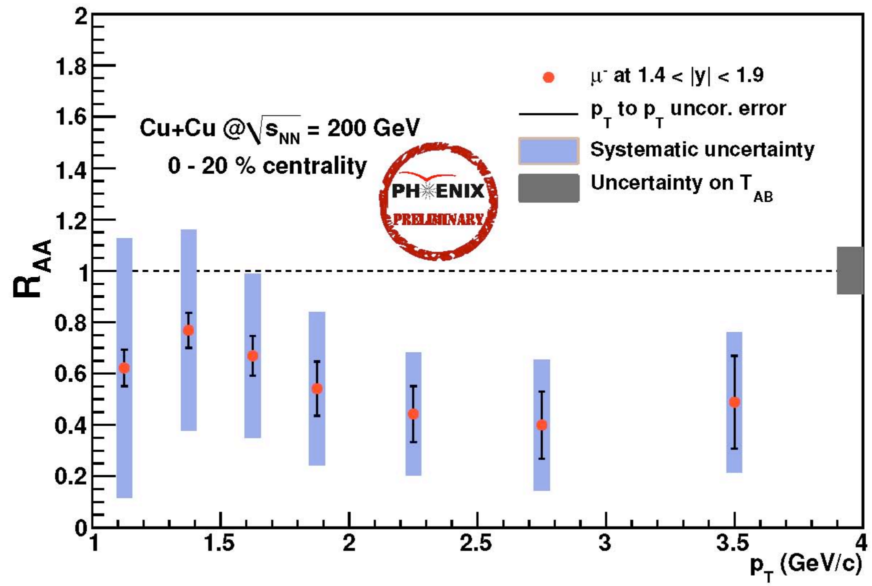




Thank you very much

PHENIX forward muons

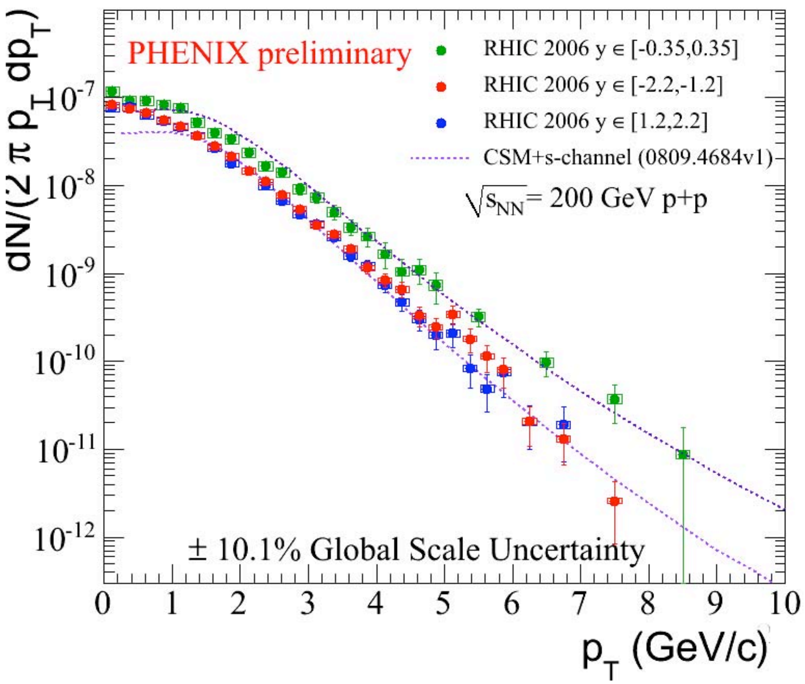


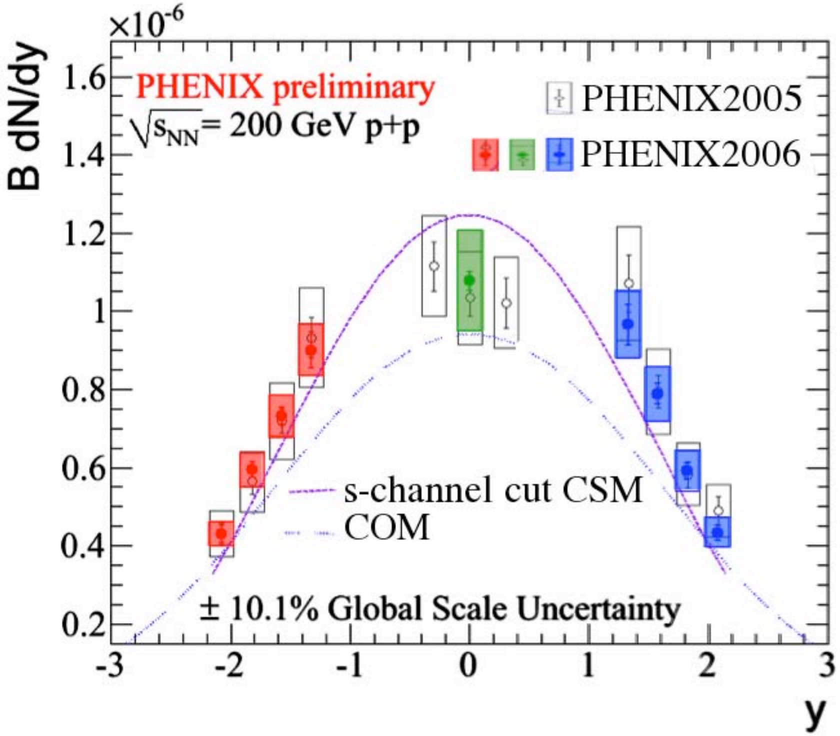


• Significant forward heavy flavor suppression

• Factor 4 larger yield than FONLL at low p_T

PHENIX J/ψ in p+p 200 GeV

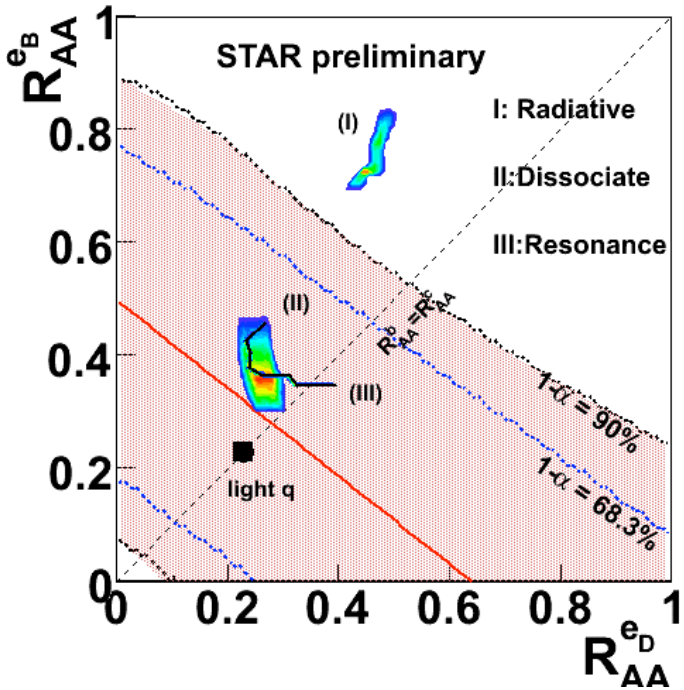




PHENIX QM09 arXiv:0907.4696

- both mid and forward results well described by the s-channel cut Color Singlet Model (CSM)

R_AA(b) vs R_AA(c)



STAR preliminary
I: Radiative
II:Dissociate
III:Resonance
(I)
(II)
(III)
light q
$1-\alpha = 90\%$
$1-\alpha = 68.3\%$
$R^b_{AA}=R^c_{AA}$
$R^{e_B}_{AA}$
$R^{e_D}_{AA}$
0
0.2
0.4
0.6
0.8
1

Conclusions

Charm measurement at RHIC Three different channels: D^0 ,μ, electrons

- **Large non-photonic electron suppression (R_AA)**
- Bottom relative contribution consistent with FONLL
- Strong high-p_T suppression in Au+Au
- Heavy quark energy loss not fully understood

J/Psi

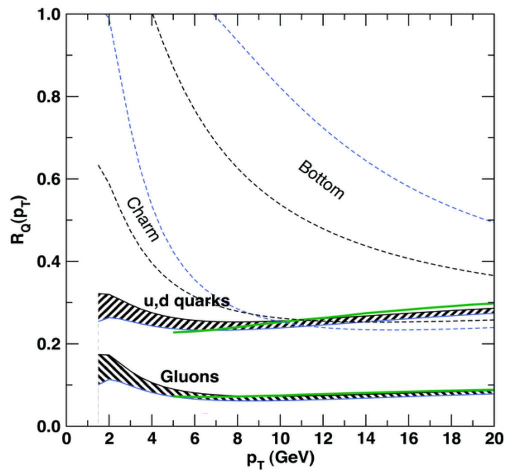
- Consistent with no suppression at high-p_T

Upsilon

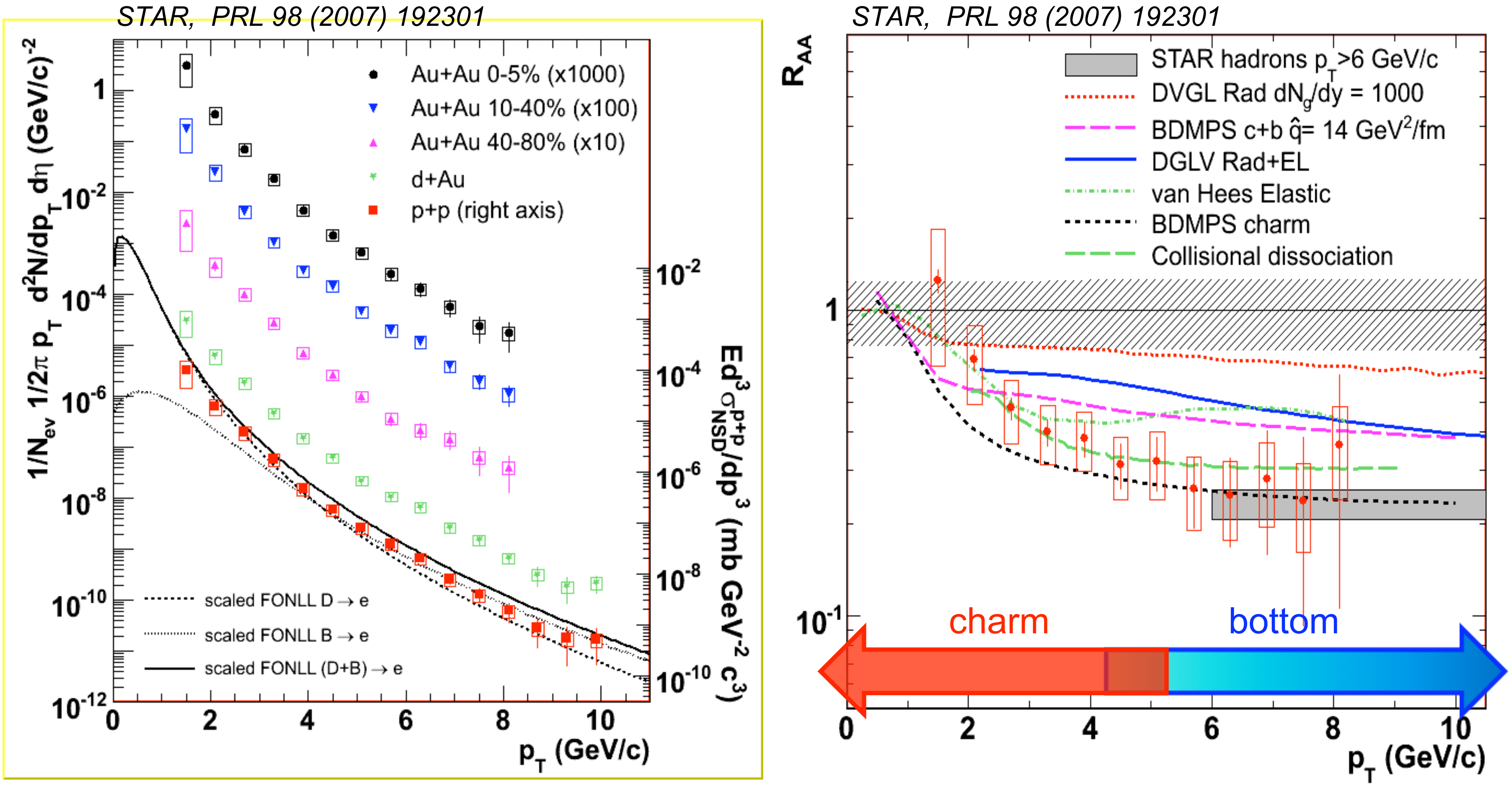
- Cross section measurement in p+p and dAu
- Follows N_{bin} scaling

R_u,d,s,c,b) vs pT

Wicks et al, Nucl. Phys. A784 (2007) 426



Suppression of non-photonic electrons



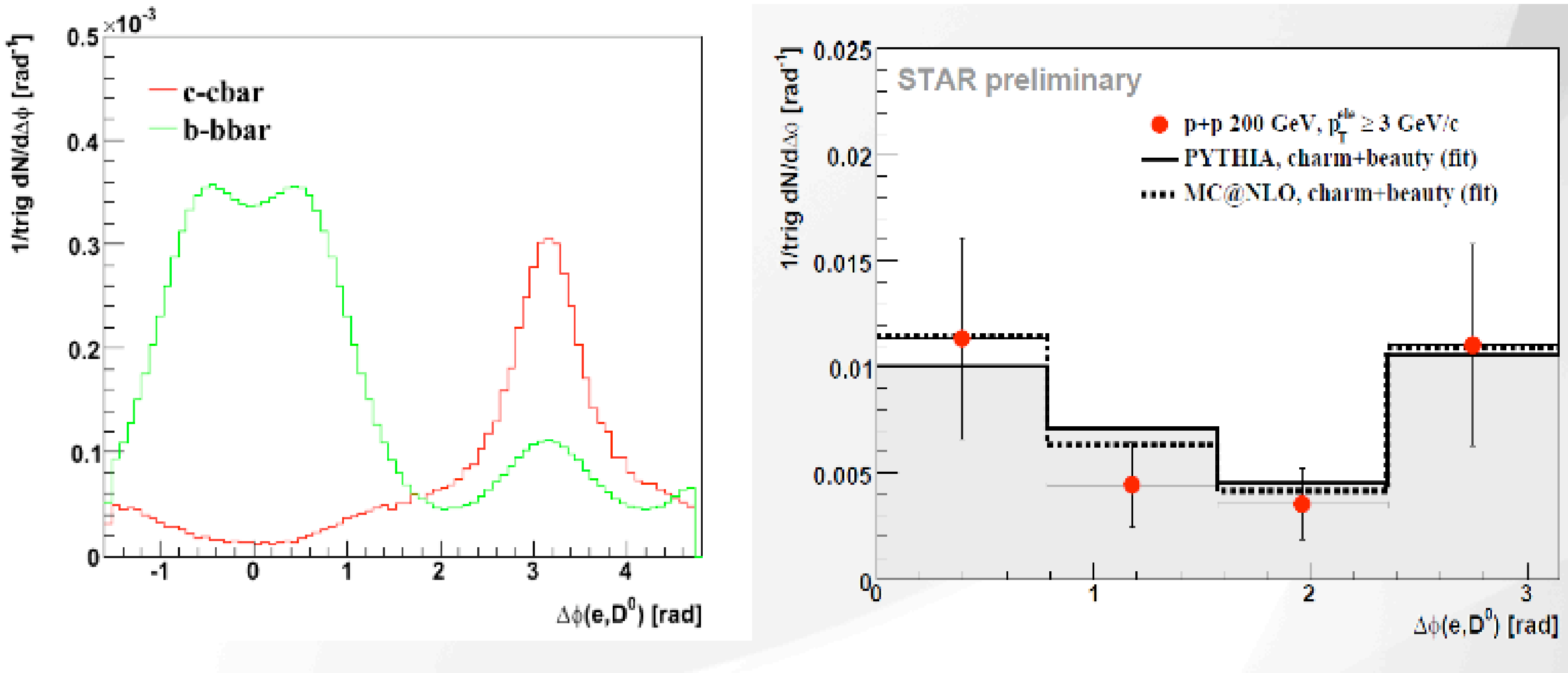
- Large suppression of non-photonics electrons similar to hadrons

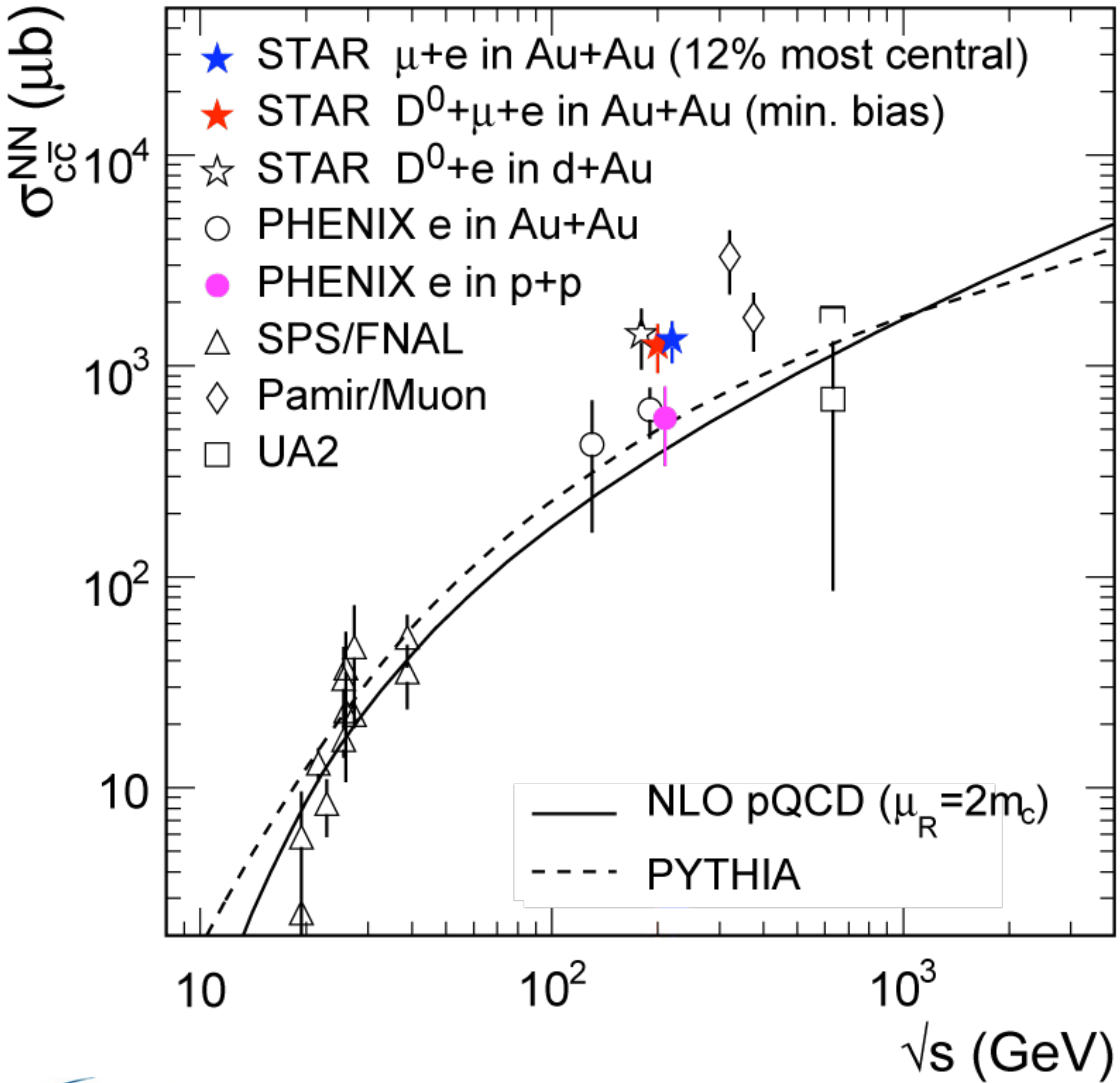
$$R_{AA}(p_t) = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$

- No satisfactory theoretical description yet

Central Au+Au 200GeV

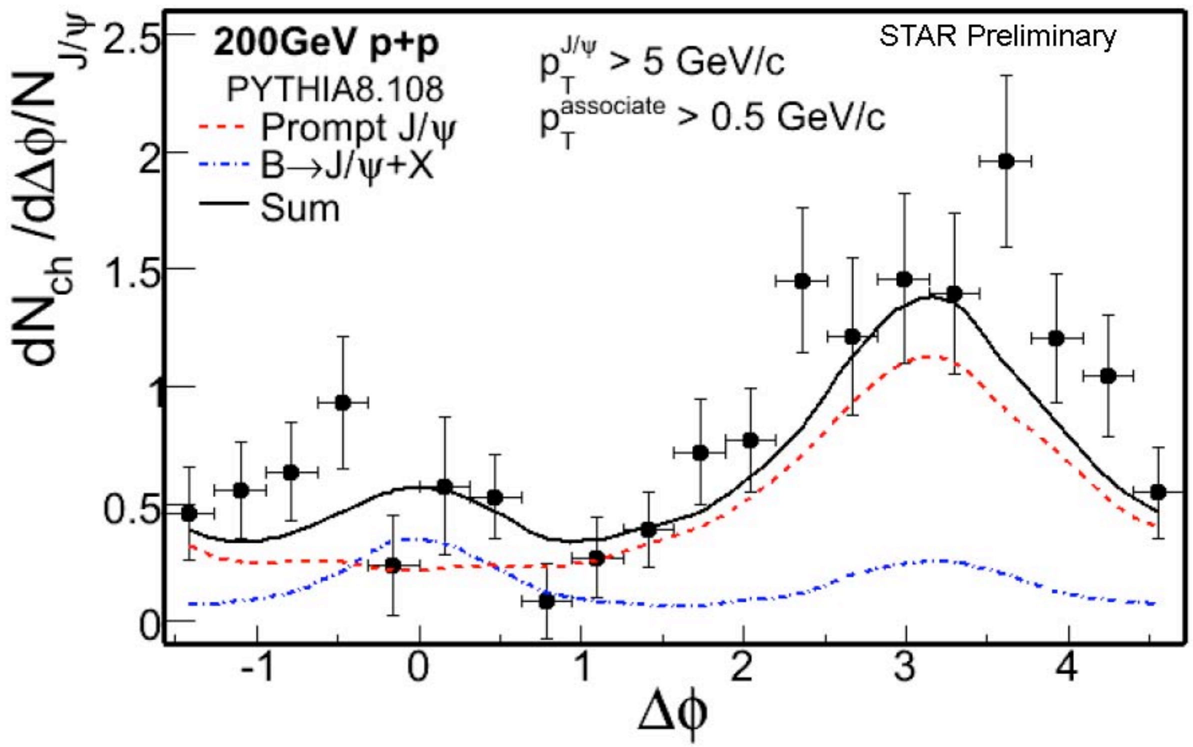
e-D0 azimuthal correlations





STAR μ+e in Au+Au (12% most central)
STAR D0+μ+e in Au+Au (min. bias)
STAR D0+e in d+Au
PHENIX e in Au+Au
PHENIX e in p+p
SPS/FNAL
Pamir/Muon
UA2
NLO pQCD (μR=2mc)
PYTHIA
σ_cc̄^NN (μb)
√s (GeV)
10
10^2
10^3
10^4

High-p_T J/ψ - hadron correlations



- Near-side correlation due dominantly to **B → J/ψ+X**
- B-meson feeddown to inclusive J/ψ production of **13%± 5%** at p_T > 5 GeV/c.

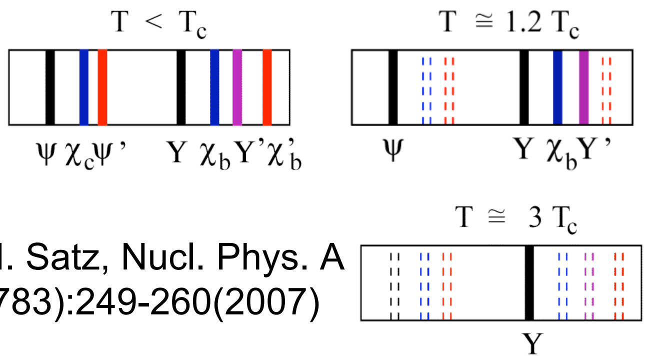
protons vs pions

- Color charge dependence: g /q   (C_A/C_F=9/4)
- Gluons loose more energy than quarks
- At high-p_T protons are produced mainly from gluon jets
- At high-p_T pions are produced mainly from quark jets

=> Expected R_{AA}(g->p) < R_{AA}(q->π)

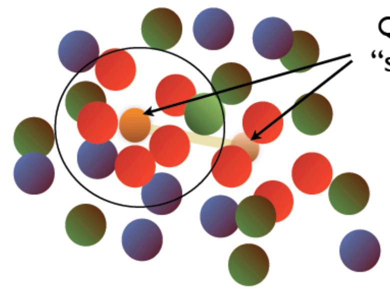
$$\langle \Delta E \rangle \sim \alpha_s\, C\, \langle \hat{q} \rangle L^2$$

Color screening and sequential suppression of quarkonia



H. Satz, Nucl. Phys. A (783):249-260(2007)

Matsui-Satz: screening the potential



Assume: medium effects described with a T-dependent potential

A. Mocsy

$$-\frac{\alpha_{eff}}{r} e^{-r/r_D(T)}$$

J/ψ suppression at low p_T maybe from excited stats (ψ', χ_c) F. Karsch, D. Kharzeev and H. Satz, PLB 637, 75 (2006); B. Alessandro et al. (NA50), Eur. Phys. J. C 39 (2005) 335; R. Arnaldi et al. (NA60), Quark Matter 2005; PHENIX: Phys.Rev.Lett.98, 232301,2007.

60% from direct J/ψ: not suppressed
30% χ_c and 10% ψ': dissociated